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Variations in Movement Patterns during Active Video Game Play in Children with Cerebral Palsy

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Abstract

Aim: Low-cost active video games (AVG) are of growing interest for use in home-based physical therapy regimes. This study investigates typical upper-limb movement patterns and variations during AVG play in children with cerebral palsy.

Methods: Sixteen children (9.5 ± 1.6 years) with hemiplegic or diplegic cerebral palsy (GMFCS Level I) participated in the study. A 7-camera Vicon MX 3D Optical Capture System was used to measure and record their upper limb movements as they played three different AVGs on the Nintendo Wii system.

Results: Play style during Wii sports games tended to be either realistic or non-realistic. All players used realistic movements when playing Wii Bowling, while 69% (n=11) and 63% (n=10) played realistically during Wii Tennis and Wii Boxing, respectively. Realistic movements tended to elicit greater use of: (a) the more proximal joints, and (b) the non-dominant/hemiplegic limb (in bilateral games). Play style may be influenced by personal or predisposing factors (e.g. MACS level, gender, experience with AVGs).

Conclusion: Movement patterns and styles vary widely between children during AVG play with the Nintendo Wii. The design of AVG-based therapies should consider these variations and their implications in order to maximize therapeutic benefit. Future studies should focus on measuring the efficacy of AVG-based therapies for home use.

Keywords: Cerebral Palsy; Rehabilitation; Physical therapy; Video game; Virtual reality therapy; Kinematics

Abbreviations: AVG: Active video game; CP: Cerebral Palsy; GMFCS: Gross Motor Function Classification System ; ICC: Intra-class correlation coefficient; MACS: Manual Ability Classification System; CI: Confidence Interval

Introduction

Active video games (AVGs) are a subset of video games controlled via gross body movements (e.g. swinging arms, stepping, dancing) as opposed to conventional hand-held devices (e.g. controllers, mouse) [1]. In addition to their recreational value, there has been increasing interest in applying AVGs to rehabilitation therapies [2-4] and physical activity promotion [5] for children with disabilities. A number of previous studies have demonstrated the effectiveness of AVGs designed specifically to address targeted therapeutic goals for individuals with cerebral palsy (CP), stroke, and spinal cord injuries [6-14]. While effective and enjoyed by children, these systems can be extremely expensive (e.g. $10,000-$50,000 [10]) and often require families to travel to a central rehabilitation facility in order to use them.

In contrast, commercially available AVG systems (such as the Nintendo Wii) are relatively low-cost (~$300) and widely available, making them particularly conducive to home-based physical therapies. Unlike custom systems however, most commercially available AVGs are not designed with specific rehabilitation goals in mind. Nevertheless, Deutsch [3] found that the Wii Sports game, when used for therapy in a structured rehabilitation setting, could improve visual perceptual processing, postural control, and functional mobility in children with spastic diplegic CP. Similarly, Saposnik [15] demonstrated the effectiveness of Wii-based rehabilitation therapy to promote motor recovery after stroke, while Mouawad [16] found that Wii-based movement therapy for stroke victims resulted in significant and clinically relevant improvements in functional motor ability.

While these are promising indications that commercially available AVGs may be applicable for home-based physical activity and therapy, a further caveat of off-the-shelf AVG systems like the Nintendo Wii is that they allow for wide variations in movement patterns between players [4]. For instance, while it is possible to play sports games (e.g. boxing, tennis) using true-to-life movements, it is often also possible to use unrealistic or "adapted" movements to achieve success in the game (i.e. flicking the wrist to emulate a tennis swing rather than moving the entire arm) [4]. This leads to a number of questions pertaining to the generalizability and suitability of AVGs for unsupervised, home-based

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physical therapy. For instance, would the use of unrealistic movements detract from therapeutic benefits in an at-home play situation in the absence of therapist guidance? Increased understanding of the variety and types of movements used during unstructured AVG play is needed in order to better appraise the potential value of AVGs like the Nintendo Wii for home-based physical therapy.

In this study, we explored the upper limb movements of children with hemiplegic CP during unguided AVG play of Wii Sports games (Wii Boxing, Wii Tennis, and Wii Bowling). The specific objectives of this study were: (1) to describe the typical patterns and variations in upper body movements elicited during AVG play, (2) to investigate the relationship between play style and use of the hemiplegic limb as relevant for achieving therapeutic outcomes, and (3) to explore personal characteristics that influence play styles during AVG play.

Methods

Participants

We recruited children (7-13 years) with hemiplegic or diplegic CP and a classification on the Gross Motor Function Classification System (GMFCS [17]) of Level I. Classification on the Manual Ability Classification System (MACS [18]) was also recorded when available. Previous studies have demonstrated that both the GMFCS and MACS have good to excellent validity and reliability in this age group [17-20]. Children were recruited from Holland Bloorview Kids Rehabilitation Hospital and ErinoakKids Centre for Treatment and Development. The study was approved by local ethics committees, and assent/consent were obtained from children and parents as appropriate. A modified Physical Activity Readiness Questionnaire was used to ensure that participants were healthy enough to engage in physical activity [21-22]. Children were excluded if they had: (i) an injury or disability that would make moderate exercise unsafe; (ii) a visual, cognitive, or auditory disability that would interfere with game play; (iii) received a botulinum toxin treatment in the last three months; (iv) orthopaedic surgxery in the last six months; (v) high blood pressure; (vi) epilepsy; (vii) chronic asthma.

Anthropometric measurements

Body mass (to the nearest 0.5 kilograms) and body height (to the nearest 0.5 centimeter) were measured and recorded (without shoes) using an upright scale (Health o Meter Inc., Bedford Heights, OH).

Active video games

Three active video games from the Wii Sports game (Nintendo, Inc., Redmond, WA) were investigated in this study: Wii Bowling, Wii Tennis, and Wii Boxing. These AVGs were selected as a representative sample of unilateral and bilateral games. Unilateral games (Wii Bowling and Wii Tennis) were played using the Wii Remote. Wii Boxing, a bilateral game, required both the Wii Remote and a second controller called the Nunchuck. The Wii Remote was held in the dominant hand (i.e. non-affected hand for hemiplegic participants). When required, the Nunchuck was held in the non-dominant hand.

Motion capture

The seven camera Vicon MX motion capture system (Oxford Metrics, Oxford, UK) was used to capture upper body movements during game play. Reflective markers (14mm spheres) were positioned at anatomical landmarks bilaterally on the upper extremities (3rd metacarpophalangeal joint, medial and lateral wrist, lateral aspect of the forearm, medial and lateral condyles of the humerus, lateral aspect of the upper arm) and shoulder girdle (left and right acromions, C7, and midpoint of the clavicles) [23]. Data were sampled at 60 Hz [24-25]. The biomechanical model consisted of 7 segments (shoulder girdle, left upper arm, right upper arm, left lower arm, right lower arm, left hand and right hand). Of note, children were also wearing surface electromyography sensors and a Cosmed K4b^2 cardio pulmonary testing unit as described previously [26].

Study procedure

Upon arrival, height and weight were recorded and the child was familiarized with the equipment and procedures. Reflective markers were positioned after which the child played the three active video games in a randomly selected order. Each game was played once for a period of eight minutes with a rest period of five minutes between each game. Children were given a maximum of five minutes to familiarize themselves with the games before playing. The entire game play session was video recorded.

Data Analysis

Kinematic analysis

A one minute segment of typical game play was analyzed for each AVG and was selected such that 'rest' periods (i.e. restarting the game, instant replays of game activities, and pauses between rounds) were minimized. The positions of retro-reflective markers were manually identified in Vicon Workstation (Oxford Metrics, Oxford, UK). Marker trajectories were filtered using a second-order Butterworth with a cutoff frequency of 6Hz [27]. Joint rotations (i.e. wrist flexion-extension, forearm pronation-supination, elbow flexion-extension, shoulder flexion-extension, shoulder abduction-adduction, and shoulder internal-external rotation) were calculated in Vicon Bodybuilder according to an established biomechanical model [28].

Movement curves were constructed to visualize the range of motion of the shoulder, elbow, and wrist joints during "purposeful movements" used to play the games (i.e. movements intended to throw a bowling ball; return a tennis ball; or throw a punch). An example of a typical purposeful movement observed in Wii Bowling is depicted in Figure 1 and extends from the instant the participant initiates his/her backswing to the instant his/her arm stops the forward motion following the "release of the bowling ball." The timing (i.e. the initiation and duration) of purposeful movements was identified via video recordings of the game play sessions. Angular positions of the joints over the duration of each purposeful movement were extracted. Movement curves for each of the games and joints were based on two randomly selected instances of the purposeful movement per participant in order to present a balanced data set that equally represents all participants while also considering some intra-subject variations.

In order to assimilate data from different participants, each of whom performed movements at different velocities, the degree of movement (e.g. elbow flexion/extension) was plotted against a normalized time value (i.e. the percentage of the movement duration) as opposed to the absolute time in seconds. This technique has been used with success in previous kinematic studies [29-30]. Motion curves (including the mean and +/- one standard deviation) were constructed in Matlab 7.11.1 (MathWorks, Natick, MA).

Video analyses

Two independent reviewers assessed video recordings of the children's AVG play sessions in order to determine:

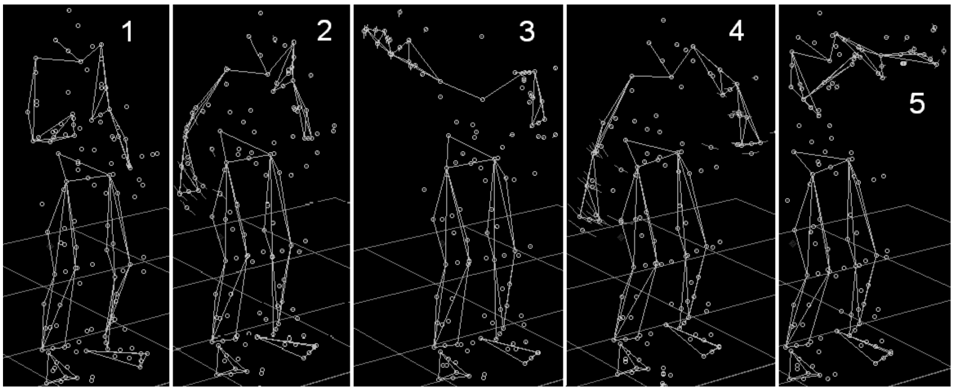


Figure 1: Typical purposeful bowling movement, showing (1) starting position, (2) backswing, (3) end of backswing/start of forward swing, (4) forward swing, and (5) end of forward motion.

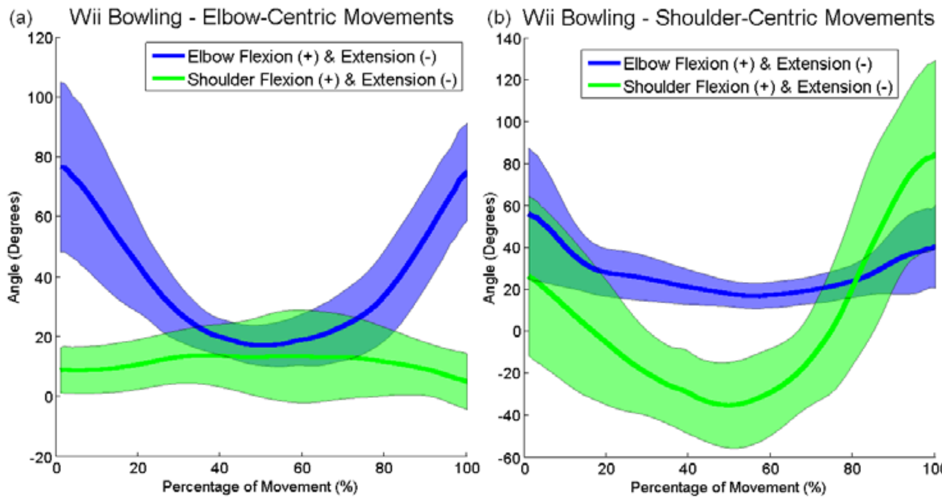


Figure 2: (a) Typical movement patterns of the elbow and shoulder during Wii Bowling game play, elbow-centric play style, (b) Typical movement patterns of the elbow and shoulder during Wii Bowling game play, shoulder-centric play style

(α) **Play style** Play style was defined as either (i) realistic (i.e. movements similar to those that would be used during 'real world' boxing or tennis), or, (ii) unrealistic (i.e. movements different from those that would be used during 'real world' boxing or tennis). Inter-rater reliability of observations distinguishing between realistic and unrealistic play styles was assessed with Cohen's Kappa (κ).

(β) **Dominant versus non-dominant limb use** Dominant versus non-dominant limb use was examined for the bilateral game, Wii Boxing, by counting the numbers of punches associated with each limb. Punching frequencies of the dominant and non-dominant limb were recorded and compared between two independent reviewers via the intra-class correlation coefficient (ICC).

Sub-group analyses

Statistical analyses were performed using SPSS v.17 with a significance level set at $p<0.05$. Independent t-tests (unequal variance) were used to explore the relationship between play style and dominant versus non-dominant limb use. Frequency counts were used to explore the relationship between play style, experience level, and gender.

Results

Participant demographics

Sixteen subjects (10 boys and 6 girls) with CP (14 hemiplegic and 2 diplegic), GMFCS Level I, were recruited to participate in the study. The average age was 9.5 ± 1.6 years. MACS levels were known for 12 of the 16 subjects, of whom 58% (n=7) were MACS Level 2 and the remainder (n=5) were MACS Level 1. A range of body mass indices (BMI) (18 ± 3 kg/cm^2) were represented with an average percentile of 57 ± 33% and a range of 10th percentile to the 95th percentile.

Typical movements patterns

Participants generally adopted either a realistic (i.e. movement that would be used in the 'real world' to succeed at these activities) or an unrealistic (i.e. movement that succeeds in the virtual world but would be unsuccessful in the 'real world' activity) play style. The play style depended both on the individual as well as the game being played. All players used realistic movements when playing Wii Bowling, while 69% (n=11) and 63% (n=10) played realistically during Wii Tennis and Wii Boxing, respectively. The κ coefficient, describing inter-rater reliability of observations pertaining to play style, (i.e. realistic or non-realistic), was 0.83±0.10 indicating excellent agreement. Of note, in Wii Boxing, participants sometimes used a mixture of realistic and unrealistic movements. Play style was categorized based on the type of movement that the child predominantly relied upon. Disagreements between observers were exclusively seen for Wii Boxing and were discussed until a consensus was reached.

Wii bowling

While all participants adopted a realistic play style for Wii Bowling, two distinct movement patterns were identified: elbow-centric movements (n=8) and shoulder-centric movements (n=8). For the elbow-centric movements (Figure 2a), the player started with the elbow flexed and with a small degree of shoulder flexion. They then extended the elbow in preparation for throwing the virtual bowling ball down the lane, while keeping the shoulder relatively motionless with respect to the torso. The elbow was then flexed to throw the ball down the lane. For the shoulder-centric movements (Figure 2b), the player started with some degree of elbow and shoulder flexion. The elbow angle was held constant through the rest of the movement as they extended the shoulder and then flexed it to throw the ball down the lane. For both movement types, the wrist was kept relatively still (i.e. limited flexion, extension, medial and lateral deviation) for most players in an attempt to prevent the ball from curving into the gutter.

Wii tennis

In Wii Tennis, 11 participants adopted realistic tennis movements. These movements were similar to the forehand and backhand movements that would be seen during 'real' tennis and primarily involved shoulder abduction and adduction and elbow flexion and extension. Of the 11 realistic players, 5 relied exclusively on backhand swings to return the virtual "ball." The backhanded swings were not reliably detected by the motion capture system. Thus, in this study, we looked solely at forehand swings. As such, Figure 3a depicts a typical forehand movement based on the 6 realistic players who performed this swing. Figure 3b describes the movements of the remaining 5 players, who used an unrealistic play style. The movements of the unrealistic players involved a similar range of elbow movement but virtually no shoulder movement. The realistic movements did not involve any regular wrist action, but the unrealistic movements tended to involve a moderate degree of wrist movement (i.e. a "flick" of the wrist) that participants performed either using wrist flexion (n=2) or extension (n=3), shown in Figure 3c.

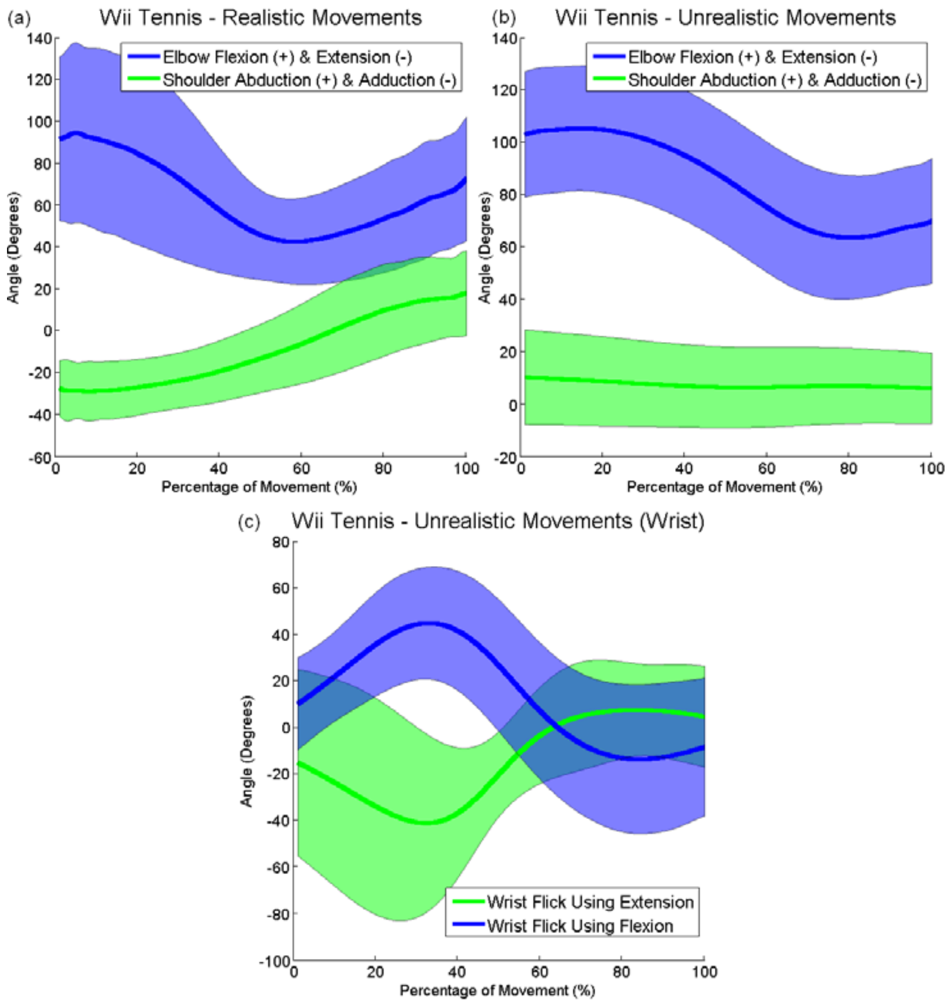


Figure 3: (a) Typical realistic (forehand) movement patterns of the elbow and shoulder during Wii Tennis game play, (b) Typical unrealistic movement patterns of the elbow and shoulder during Wii Tennis game play, (c) Typical unrealistic movement patterns of the wrist during Wii Tennis game play

Of note, the unrealistic movements were significantly faster than the realistic tennis movements. The realistic movements took, on average, 0.607±0.168 seconds to complete a swing, while the unrealistic movements took only 0.189±0.026 seconds ($p < 0.001$).

Wii boxing

Lastly, for Wii Boxing, movements occurred in bursts at a much higher frequency and as such, the movement curves presented in Figure 4 depict a series of two consecutive punches. Similar to Wii Tennis, Wii Boxing movement patterns were divided between those participants who used realistic movements (n=10) and those using unrealistic movements (n=6). The realistic movements primarily involved regular elbow flexion and extension, as shown in Figure 4a. The unrealistic movements, on the other hand, involved a much smaller range of elbow flexion and extension, which was compensated for by the use of regular wrist flexion and extension, shown in Figure 4b. No regular patterns of shoulder movement were found for either play style. Interestingly, as in Wii Tennis, the unrealistic play style also allowed participants to increase their punching frequency: a series of two realistic punches (as shown in Figure 4a) took, on average, 0.922±0.221 seconds, while a series of two unrealistic punches (Figure 4b) took only 0.419±0.072 seconds ($p < 0.001$).

Dominant versus Non-dominant/hemiplegic limb use during Wii boxing

Inter-rater reliability for video analyses of punching frequency during Wii Boxing was strong with an ICC of 0.98 (95% confidence interval [CI]: 0.91-0.95, p<0.001) for the dominant (i.e. non-hemiplegic) arm and an ICC of 0.96 (95% CI: 0.85-0.98, p<0.001) for the non-dominant arm. Significant differences related to the play style were found between dominant and non-dominant limb use during Wii Boxing (see Figure 5). Participants who used unrealistic movements punched with a higher frequency (i.e. approximately 41% higher) with their dominant arm than those using realistic movements (p=0.006). This is not surprising given that an unrealistic punch can be completed in less than half the time required for a realistic punch. Conversely, participants who used realistic movements punched with a higher frequency (i.e. approximately 35% higher) with their non-dominant/hemiplegic arm than those who used non-realistic movements (p=0.043), despite the fact that the duration of a realistic punch is greater than that of a non-realistic punch.

Experience levels, gender, and play style

In Wii Tennis and Wii Boxing, where realistic versus unrealistic movement patterns were observed, 6 of the 11 participants with previous Wii Sports experience used unrealistic movements for at least one of the AVGs. Only 1 of the 5 inexperienced players used unrealistic movements during AVG play. In terms of gender, 6 of the 10 male participants used unrealistic movements for at least one of the games, while only 1 of 6 female participants used unrealistic movements. Interestingly, participants who used unrealistic movements in one of the games also tended to use them in the other (p = 0.018).

Discussion

Key findings and clinical implications

This study examined the upper limb movements of children with CP while playing three different AVGs: Wii Bowling, Wii Tennis, and Wii Boxing. Key findings and implications are as follows:

Different patterns of movement were observed that varied with game, play style, and individual

Children used both realistic and unrealistic movements when playing sports games (i.e. Wii Boxing and Tennis) on the Nintendo Wii. Unrealistic movements tended to involve decreased motion of the proximal joints (e.g. the shoulder in Wii Tennis and the elbow in Wii Boxing) and greater use of the distal joints (e.g. the elbow in Wii Tennis and the wrist in Wii Boxing). Unrealistic movements required significantly less time to perform than realistic movements, giving children a competitive advantage in the games, particularly Wii Boxing. Even when a realistic style of play was consistently used (i.e. for Wii Bowling), distinct variations in the children's movement patterns were still observed (e.g. elbow versus shoulder centric).

Clinical implications

If the therapeutic goal of an AVG-based therapy is to engage a child in repetitive practice of a specific motion, then it may be necessary to

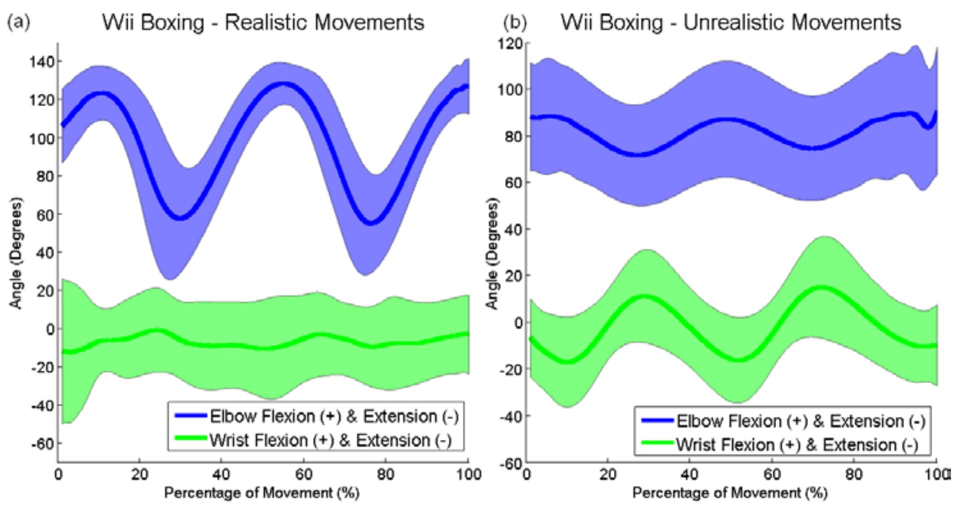
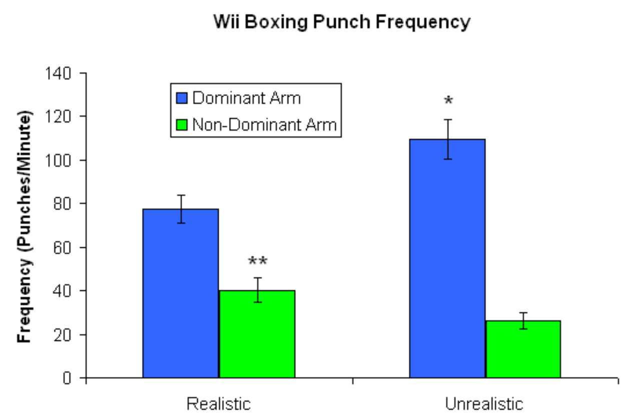


Figure 4: (a) Typical realistic movement patterns of the elbow and wrist during Wii Boxing game play, (b) Typical unrealistic movement patterns of the elbow and wrist during Wii Boxing game play



* Dominant arm frequency is significantly higher for unrealistic movements (p=0.006)
** Non-dominant arm frequency is significantly higher for realistic movements (p=0.043)

Figure 5: Dominant vs. non-dominant arm use in Wii Boxing. Error bars depict standard errors.

provide explicit directions not only on the types of games to be played, but also on the play style to be used; for instance, if the therapeutic goal is to practice wrist extensions, which is clinically relevant to improve hand function in children with hemiplegic CP [31], then Wii Boxing played in the non-realistic style could be an appropriate prescription. Alternatively, it may be necessary to design and explore more targeted games or other commercially available systems (e.g. camera-based systems like Microsoft's Kinect or Sony's EyeToy) to ensure that the intended movement is indeed being practiced as opposed to an alternative movement that produces the same (or sometimes better) results in the virtual environment. Of note, home-based AVGs, like the Nintendo Wii, do engage the child in complex motor tasks that may still promote high levels of corticospinal excitability that could lead to functional improvements [32] even in the absence of well-controlled, repetitive practice. Future research is needed to quantify if, and to what extent, AVG play impacts function and if so, the underlying mechanisms driving these changes.

Differences in the frequency of dominant versus non-dominant arm use were found based on play style

In Wii Boxing, a bilateral game, children who adopted an unrealistic play style tended to complete a greater proportion of their punches using their dominant limb as opposed to their non-dominant limb than children who used a realistic play style. This observation is likely linked to the child's motivations during play. It may be that some children adapt non-realistic movement patterns in an effort to succeed in the game as it enables them to punch at a higher rate. For the same reason, this group of children may also rely more exclusively on their stronger, dominant limb. **Clinical Implications** One of the most promising aspects of AVG-based therapies is that they appeal to children's (and adults') motivations to play. However, the child's motivations to succeed in the game may at times conflict with the therapeutic goals of the activity. In some cases, it may be enough for therapists and/or parents to remind children of the longer-term functional benefits that may be achieved when the non-dominant or hemiplegic limb is engaged in the game play. In other cases, it may be necessary to adjust the play environment or in-game rewards to encourage use of the desired limb. Li [11] present one example of such a system.

Play style may be influenced by previous experience with AVGs and gender; children who use an unrealistic style in one game are likely to do so in others

Although the sample size was too small for a rigorous statistical analysis of subgroups, males and experienced players appeared to adopt an unrealistic play style more frequently then females and less experienced players. Children who used unrealistic movements in one game also tended to use them in others. **Clinical Implications** These findings again indicate that AVGs may be used very differently by different children and that some of these variations may be explained via personal/predisposing factors. Despite the great need for systematic evaluation of home-based rehabilitation, this variability may make it difficult to measure the effectiveness of AVG-based therapies in the home environment and should be a focus of consideration in the design of interventions and evaluations.

Limitation

Due to the limited sample size of this study, sub-group comparisons (i.e. gender, experience level) were limited. Frequency counts were provided primarily to explore and identify potential areas of interest for future studies with larger sample sizes. For Wii Tennis, the reflective markers tended to be occluded during "backhand" movements and as such, there was insufficient data to perform an analysis of this movement. The results of this study are only applicable to children with GMFCS Level 1. For consistency, all subjects started the AVGs at a beginner level which may have been too easy for some of the more experienced players. Increasing the difficulty level (i.e. to their actual skill level) and/or duration of play may also have resulted in different movement patterns emerging.

Future work

As more off-the-shelf AVGs continue to become available, it would be useful to examine the movement patterns that other games and systems elicit. Identifying the "active ingredients" of any therapy is essential to increasing its effectiveness [33]. As such, it is important to better understand the typical movements and variations that occur in AVGs under consideration or in use for therapy. To our knowledge, this is the first study to investigate variations in typical movement patterns elicited during AVG play. Variations in movement patterns in children with a greater range of MACS and GMFCS levels, other disabilities, as well as typically developing children, may be of interest for future work. Studies with larger sample sizes may also enable more in-depth explorations of causal factors associated with variations in play styles between subgroups (e.g. gender, experience, functional abilities). In addition, for the unilateral games, it would be interesting to investigate movement patterns of the hemiplegic limb when it is used for game play rather than the dominant limb. Functional outcomes must also be evaluated to assess the efficacy of AVG-based therapies. A multitude of factors need to be better understood if AVGs are to be effectively used for physical rehabilitation in the home including the influence of game level/difficulty, the intensity and duration of play, together with long-term adherence and enjoyment.

Conclusion

Movement patterns and play styles vary widely between children during AVG play with the Nintendo Wii. These variations are important to understand and to consider in the design of effective AVG-based therapies to be used in the home environment. Future work should be focused on measuring the efficacy of AVG-based therapies and on creating novel solutions that capitalize on the popularity of low-cost, commercially available systems for in home use, while maximizing their therapeutic benefit.

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