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Exploring children's movement characteristics during virtual reality video game play

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A B S T R A C T

There is increasing interest in the use of commercially-available virtual reality video gaming systems within pediatric rehabilitation, yet little is known about the movement characteristics of game play. This study describes quantity and quality of movement during Nintendo Wii and Wii Fit game play, explores differences in these movement characteristics between games and between novice and experienced players, and investigates whether motivation to succeed at the game impacts movement characteristics. Thirty-eight children (aged 7–12) with and without previous game experience played Wii (boxing and tennis) and Wii Fit (ski slalom and soccer heading) games. Force plate data provided center of pressure displacement (quantity) and processed pelvis motion indicated smoothness of pelvic movement (quality). Children rated their motivation to succeed at each game. Movement quantity and quality differed between games ($p < .001$). Children with previous experience playing Wii Fit games demonstrated greater movement quantity during Wii Fit game play ($p < .001$); quality of movement did not differ between groups. Motivation to succeed did not influence the relationship between experience and outcomes. Findings enhance clinical understanding of this technology and inform the development of research questions to explore its potential to improve movement skills in children with motor impairments.

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1. Introduction

The application of virtual reality systems as therapeutic interventions to improve movement abilities in children with motor impairments is a promising area of research in pediatric rehabilitation (Parsons, Rizzo, Rogers, & York, 2009; Sandlund, McDonough, & Hager-Ross, 2009). Virtual reality is defined as "the use of interactive simulations created with computer hardware and software to present users with opportunities to engage in environments that appear to be and feel similar to real world objects and events" (Weiss, Rand, Katz, & Kizony, 2004). Yet the substantial cost and commercial unavailability of immersive virtual reality systems, which may include head-mounted displays or force feedback gloves, limits the applicability of this complex technology within mainstream clinical practice (Rizzo & Kim, 2005). In contrast, motion-capture virtual reality systems in which the user's image is reflected within the virtual environment, or the user is represented as an avatar within the virtual environment, may offer more promise for integration on a wider scale. Many motion-capture systems have been designed specifically for rehabilitation purposes (Weiss et al., 2004). However, researchers are increasingly investigating the feasibility and effectiveness of lower-cost, commercially available technologies, such as virtual reality video gaming systems, as potential rehabilitation interventions (Chen et al., 2007; Deutsch, Borbely, Filler, Huhn, & Guarrera-Bowlby, 2008; Flynn, Palma, & Bender, 2007; Halton, 2008; Jannink et al., 2008).

The Nintendo Wii and Wii Fit[2] are interactive and movement-based virtual reality video gaming systems that are being used within a variety of rehabilitation settings (Coyne, 2008; LaViola, 2008; Tanner, 2009; The Associated Press, 2008; Zyga, 2007). In these systems, the player is represented through a third person point of view as an avatar within the virtual environment. A hand-held remote measures users' movements, which are translated onscreen; the remote detects changes in acceleration and orientation and the system adjusts feedback accordingly (Deutsch et al., 2008). Wii Sports games such as tennis and baseball involve movement and use of the remote controller in ways that are similar to completing the actions in real life (Deutsch et al., 2008). The Wii Fit is a pressure-sensitive balance board on which players weight shift to control their avatar's movement on screen. The Wii remote provides haptic feedback and games provide abundant visual and auditory feedback, opportunity to compete against multiple players, high quality graphics, and games with a pre-set progression in difficulty levels (Deutsch et al., 2008). Recent advances in Wii technology, such as new movement-based options (Wii Sports Resort, which includes games such as archery, canoeing, and basketball (Nintendo Inc., 2009)) and an addition to the remote (Wii MotionPlus, which increases the accuracy of three-dimensional motion capture (Nintendo Inc., 2009)) suggest that continual upgrades to this gaming system may motivate long-term rehabilitation use.

A 2008 case study in *Physical Therapy* outlining the use of the Wii Sports games in the rehabilitation of an adolescent with CP is the first peer-reviewed report to evaluate this gaming system (Deutsch et al., 2008). This study describes how outcomes of visual perceptual processing, balance, and functional mobility improved after using the Wii in eleven training sessions over a two month period. The authors provide a detailed description of each of the five Wii Sport games and their training modes. They also outline the potential therapeutic uses of the games as well as a qualitative description of movements required by the user during game play (Deutsch et al., 2008).

As these games have only recently been introduced to clinical practice, rehabilitation professionals may still be uncomfortable with the notion of using video games to promote movement abilities in children with motor impairments. Therapists seeking information to support their clinical decisions may benefit from a better understanding of the "active ingredients" of these interventions (Whyte & Hart, 2003). Whyte and Hart (2003) argue that the content and mechanisms of rehabilitation interventions have rarely been objectively defined, and that their active ingredients, which are the essential components of an intervention that are hypothesized to relate to its outcomes or effects, are often poorly understood. Of fundamental interest to therapists are the movement opportunities offered by Wii and Wii Fit game play. The motivational element of including video games within interventions is also of appeal. Therefore, potential active ingredients of use of these gaming systems within motor

[2] Nintendo of Canada Ltd. Suite 110, 13480 Crestwood Pl, Richmond, BC, V6V2J9.

rehabilitation are the movement characteristics of game play and the relationship between these characteristics and player motivation. We chose to begin exploring these active ingredients in children without motor impairments as the first step in a research program in this area.

The two movement characteristics of interest to this study are the amount of center of pressure displacement during game play (movement quantity), and the smoothness of motion, as measured at the pelvis (movement quality). These characteristics are relevant to therapeutic decision-making specific to use of these gaming systems to promote movement abilities in children with motor impairments. For example, therapists may be interested in using these games to promote dynamic balance skills or to train efficient and smooth movement patterns. Objectively analyzing these movement characteristics in healthy children during video game play may facilitate increased clinical understanding of their movement requirements, contributing to the development of research questions informing clinical decision-making with respect to use of these games in clinical practice for children with motor impairments.

Movement quantity and quality may be impacted by features related to the intended commercial usage of these gaming systems. Indeed, users familiar with the Wii Sport games understand that movement during game play can vary widely between players. Although full body movement is one option for Wii Sport game play, game success can also be achieved by simply using one's wrist to manipulate the remote controller. This potential for "cheating," often discovered through experience, or through observing the playing styles of others, may be attractive to children, and may impact the potential of these Wii Sport games as unsupervised home therapy interventions. Although this is less of an issue for the Wii Fit games, given that body movement is required for game play, these anecdotal observations of changes in movement characteristics with game play experience require exploration.

Virtual reality video games are often described as motivating for children and youth (Deutsch et al., 2008; Sandlund et al., 2009). This increased motivation to practice may lead to more repetitions or longer practice duration. In a study with four adult players, Pasch et al. indicated that player motivation was related to the movement strategies that they employed during Wii boxing game play (Pasch, Berthouze, van Dijk, & Nijholt, 2008). Little is known as to whether motivation influences children's movement characteristics during video game play. Given that game success is a salient outcome for children, we chose to explore motivation to succeed at the game and its relationship to movement characteristics in this study.

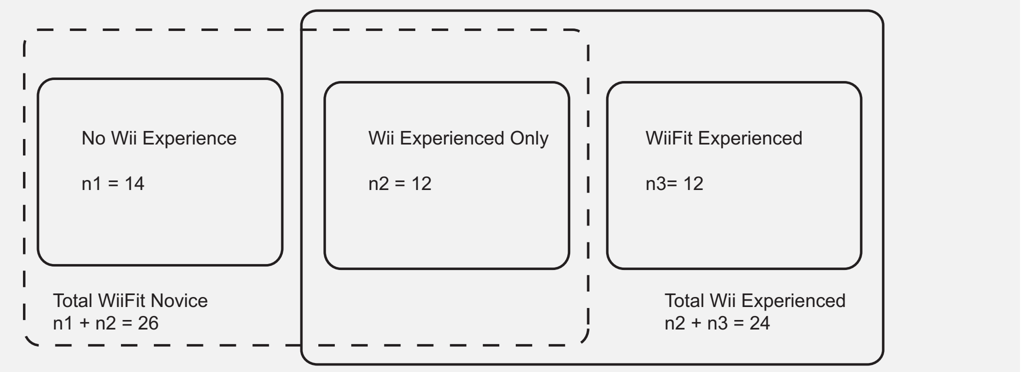
The purpose of this study is to describe how children move while playing four different Nintendo Wii and Wii Fit games. Our primary research objectives are to describe the quantity of center of pressure displacement and the quality of pelvic motion involved in game play, and to determine if these characteristics differ between games, between game play trials, and between children with different amounts of play experience. The secondary objective is to explore the influence of the child's motivation to succeed at the game on movement quality and quantity outcomes, as mediated by previous experience.

2. Methods

2.1. Participants

Children between the ages of 7 and 12 years were recruited from the local population. Inclusion criteria were normal or corrected to normal vision and hearing, age appropriate grade at school with no support from an educational assistant, and ability to understand English. Exclusion criteria were the presence of a known musculoskeletal, neurological, or developmental medical condition, a history of seizure(s), or the presence of a seizure disorder. Children were grouped based upon their previous experience with the Wii and Wii Fit systems, which was determined by parent report of duration of system ownership and approximate number of hours played per week. Novice and experience groupings were created for the Wii platform and the Wii Fit platform (see Table 1 for details). Parents completed a demographic questionnaire providing information about their child's age, grade in school, height, weight, experience with the Wii and/or Wii Fit, and participation in recreational and competitive sports activities. The study received ethical approval from the Hamilton Health

Table 1
Groupings for statistical analysis.*



* Note that grouping varies depending on platform.

Science/McMaster University Faculty of Health Sciences Research Ethics Boards. All parents provided informed consent and children provided informed assent prior to participation.

2.2. Procedure

Testing was performed in the Human Movement Laboratory at McMaster University. Participants played two Nintendo Wii Sport (boxing and tennis) and two Nintendo Wii Fit games (soccer heading and ski slalom) in a randomized order. Table 2 describes characteristics of these four games. Given that three other Wii Sport games and seven other Wii Fit balance games exist, the games chosen for this study do not represent the full possibilities of both platforms, and our intent was not to compare the two platforms.

During game play, children wore a rectangular sensor pack over their sacrums which was snugly secured with an elastic belt around their hips. The sensor pack was connected via two cables to a control console. Twelve light emitting markers were placed on the rear, right, and left sides of the sensor pack and the children played the games within the line of sight of an optoelectronic motion-capture system (Northern Digital Inc., Waterloo, Canada). The motion of the markers was captured at 100 Hz and was used to measure the three-dimensional position and orientation of the sensor pack. Each child played the boxing, soccer heading and ski slalom games while standing on a force plate (50.8 cm × 46.4 cm; OR6, Advanced Mechanical Technology, Inc., Watertown, MA). For the two Wii Fit games, the Wii Fit balance board (20 cm × 40 cm) was placed on top of the force plate. Force plate data were not collected during tennis game play as children were free to move within the range of the camera view. The sensor pack motion and the force plate data were synchronously collected. The vertical offset between the top of the Wii Fit balance board and the location of the sensors within the force plate was taken into consideration using "plate padding" formulae (as detailed at www.kwon3d.com). The force plate outputs were also frequently zeroed at those time periods with no known load to correct for sensor drift. A television screen (Sony Trinitron, 32″) on which each child viewed their avatar within the game environment was positioned 120 cm in front of the force plate at eye level. Fig. 1 provides an illustration of the experimental set-up, while Table 3 further details the experimental methods.

The order of game play was assigned using a pre-defined random sequence (obtained using rand() within Microsoft Excel). Four possible combinations were created according to participant age (7–9 years versus 10–12 years) and game play experience (novice versus experienced) to balance game presentation order across these four groups. The participant's score on each trial was recorded. The duration of testing sessions was approximately 30–45 min. Children were asked to rate their motivation to succeed at the game by answering the question, "On a scale of 0–7, with 0 meaning that you

Table 2
Characteristics of the Wii and Wii Fit games used in this study.

	Tennis	Boxing	Soccer	Skiing
Description of game as used in the study	Participant controlled the movements of both of the players on their side, holding the Wii remote in their dominant hand	Training level 1 (“working the bag”). The Wii remote was held in the dominant hand and the second controller (the “nunchuck”) in the non-dominant hand. The player punches a virtual punching bag until it is knocked off the chains and is replaced with another bag	Novice level. Soccer heading involves lateral weight shifting to head soccer balls while also avoiding being hit by other objects	Novice level. The ski slalom game involves lateral and anterior/posterior weight shifting to navigate through the gates of a virtual downhill ski course
Rationale for inclusion in study	Dynamic; high potential for movement as compared to golf or bowling	Dynamic, need for bilateral upper extremity movements. Training level selected because during the actual game players can be “knocked out”, resulting in unpredictable periods of limited movement during data collection	Fixed duration of play; immediately available on Wii Fit system. Other balance games require ‘unlocking’ which only happens after a certain amount of practice with the system	
Movement restrictions	No restrictions in movement, player allowed to choose their movement strategy from minimal wrist movement to whole body movement*	No restrictions in movement; player allowed to choose their movement strategy**	Player must stand on Wii Fit board, therefore foot movement is restricted. Capability to grade weight shifting and body movement over feet but game success tied to choice of correct weight shifting strategy	Player must stand on Wii Fit board, therefore foot movement is restricted. Capability to grade weight shifting and body movement over feet but game success tied to choice of correct weight shifting strategy
Amount of variability in task condition	Large variability; responding to opponents; unpredictable task conditions that change over trials	Minimal variability; target mostly stationary and task does not change from trial to trial	Moderate variability; 3 defined conditions in which the soccer ball is presented (left, center, right), random order that soccer balls or other objects are directed to the player, different between trials	Minimal to moderate variability; slalom course stays the same from trial to trial and the player can plan ahead with visual notice of next gate, however the speed can vary
Amount of feedback and instructions (KP = knowledge of performance; KR = knowledge of results)	*Before*: no instructions *During*: continuous KP, visual, auditory and tactile feedback, KR *After*: KR, Mii affect	*Before*: written instructions *During*: KP, visual and auditory feedback, visual cues *After*: KR (score)	*Before*: written instructions *During*: prompts/written cues, KP, visual and auditory feedback *After*: KR (score and Mii affect, ranking)	*Before*: written instructions *During*: written cues, continuous KP for center of gravity, visual and auditory feedback *After*: KR (score, Mii affect, ranking)
Minimal movement required for game	Unilateral upper extremity to control	Bilateral upper extremity to control	Full lateral weight shifting of center of	Anterior–posterior and lateral weight

(*continued on next page*)

Table 2 (*continued*)

	Tennis	Boxing	Soccer	Skiing
success	remote velocity in 3D space (velocity dependent, not amount of movement)	remote and nunchuck in 3D space (velocity dependent, not amount of movement)	gravity over base of support	shifting of center of gravity over base of support
Player perspective	Third person raised 'behind the back' perspective	Third person, transparent "behind the back" perspective	Third person, transparent "behind the back" perspective	Third person, transparent "behind the back" perspective
Progression in difficulty	System determined; system adjusts difficulty based on player's skill level	Same difficulty for all	User determined; 3 levels are available, user chooses which to play	User determined; 3 levels are available, user chooses which to play
Game duration	Determined by children's success	Trial duration of one minute		
Score	A skill level score is created by the Wii system after each game	The score equals the number of bags knocked off during each game	A score is calculated by the Wii Fit system per game based on number of balls headed (more points for consecutive hits); points are deducted for being hit by other objects	A score is calculated by the Wii Fit system per game based on time to navigate the course and the number of missed gates

* Players were confined to a space approximately 2.5 m wide while playing Wii tennis.
** Players were confined to the force plate (50.8 cm × 46.4 cm) while playing Wii boxing.

Fig. 1. Experimental set up: participant playing the Wii Fit soccer heading game.

Table 3
Experimental set-up.

Variable	Tennis	Boxing	Soccer Heading	Ski Slalom
Number of trials	1 practice game; 3 single games for data collection	1 practice trial, 3 trials for data collection		
Set up	Two strips of tape were placed on the ground to represent the limits of the camera's line of sight	Participants stood on the force plate. A 5 cm carpet border around the force plate was used to provide a tactile reminder to remain within the force plate	Participants stood on the Wii Fit balance board which was situated on the force plate	
Movement restrictions	The participant was instructed to move as much as they wanted during game play within the lines	Participants stood on the force plate and were instructed not to step outside of its boundaries	Participants stood on the Wii Fit balance board	
Creation of "Mii" (avatar)	A Mii was created for each participant prior to the testing session and deleted immediately after testing was completed			
Verbal instructions	Participants received standardized instructions prior to their initial trial to participate in the game as though they were actually playing tennis or boxing in real life		Visual instructions provided on screen were read aloud to the participant	
Verbal Feedback	Standardized positive feedback (e.g. "good job") was provided to the participant after each trial, regardless of game success. The parent was asked not to provide additional verbal feedback or instruction to their child			

really didn't care about doing well at the game, and 7 meaning that you cared "A LOT" [verbal emphasis] about doing well at the game, can you tell me how much you wanted to do well at the game?"

2.3. Outcomes

Two movement outcomes were used in this study. Quantity of movement was defined as the excursion length (in meters) of displacement of the path of the child's center of pressure as measured using the force plate data. Longer path lengths (greater displacement) indicate greater motion quantity. Quality of pelvic movement was defined as the motion (three-dimensional displacement) of the centroid of the 12 pelvic markers, twice differentiated, then manipulated to obtain resultant and tangential accelerations. The ratio of the sum of the resultant pelvic accelerations squared and the sum of the tangential accelerations squared provided an index of movement quality called the ALR. Larger ALR values indicate less smooth movements, which reflect poorer movement quality (Pierrynowski, 2009). ALR values cannot be less than 1 nor greater than 2π; a value of 1 represents smooth movement.

2.4. Statistical analysis

The primary objective of this study was to determine if the quantity and quality of movement of children playing Wii and Wii Fit games differed between games, between experienced and novice players, and between trials of each game. Two one-way analyses of variance (ANOVA) were undertaken to evaluate game differences for movement quantity (path length) and quality (ALR) for the study sample as a whole (comparing 4 versus 3 games, respectively). The Scheffé post-hoc multiple comparison test was used to identify individual game differences. Subsequently, for each game, for each outcome, a two-way repeated measure ANOVA was used to identify experience and trial differences.

The secondary objective of the study was to determine if quantity and quality of motion outcomes for the novice and experienced groups were influenced by motivation to succeed at the game. ANCO-

VAs were performed on statistically significant findings of between-group differences. Statistical analysis was performed using SPSS version 17.0, significance level was set at $p \leqslant .05$ and post-hoc power calculations were requested.

3. Results

3.1. Participant demographics

Thirty-eight children (22 males and 16 females) were included in the analysis. Descriptive statistics were used to characterize the study sample. Table 4 provides characteristics of the study groups.

3.2. Per game differences: study sample as a whole

The movement quality (ALR) and quantity (path length) outcomes differed between games ($F(3, 440) = 6.34$, $p < .001$, Power = .967 and $F(2, 338) = 59.55$, $p < .001$, Power = 1.00, respectively). The post-hoc test indicated significant differences between only soccer and tennis (mean difference = 0.196, $SE = 0.045$, $p < .001$) for ALR while for path length all three games differed from each other (boxing-soccer, mean difference = 4.77, $SE = 1.42$, $p = .004$; soccer-skiing, mean difference = 10.32, $SE = 1.41$, $p < .001$; boxing-skiing, mean difference = 15.09, $SE = 1.41$, $p < .001$). Boxplots of this data are provided in Figs. 2 and 3. Note that for boxing some children had outcomes dissimilar to their peers. These "outliers" were not removed from the analysis given that the intent was to capture the range of movement variability. The boxplots illustrate the considerable between-participant variability in movement quality within each game, with much less between-participant variability in movement quantity within each game.

3.3. Per game differences between novice and experienced players

Table 5 demonstrates means and standard deviations of ALR and path length values for each game for each group. No main effect of experience on path length was found for boxing ($F(1, 107) = 1.842$, $p = .178$, Power = .270. No main effect of experience on ALR was found for either boxing or tennis (F(1,

Table 4
Descriptive characteristics of study sample.[*]

Variable	Full sample	Wii – novice	Wii – experience	Wii Fit – novice	Wii Fit – experience
Number	38	14	24	26	12
Age (years)	10.02 (SD = 1.55)	10.25 (SD = 1.56)	9.88 (SD = 1.56)	10.03 (SD = 1.66)	9.97 (SD = 1.36)
Gender	M = 22 F = 16	M = 8 F = 6	M = 14 F = 10	M = 13 F = 13	M = 9 F = 3
BMI (kg/m^2)	17.79 (SD = 3.71)	16.82 (SD = 2.74)	18.27 (SD = 4.08)	17.55 (SD = 3.84)	18.29 (SD = 3.56)
Extracurricular sports activities (h/week)[**]	3.84 (0–14)	3.61 (0–10)	3.95 (0–14)	3.62 (0–14)	4.29 (1–7.5)
Duration of Wii system ownership (months)	9.92 (0–24)	0	15.71 (6–24)	6.23 (0–18)	17.92 (6–24)
Average past practice with Wii Sports games (h/week)	0.62 (0–3)	0	0.98 (0–3)	0.33 (0–2)	1.25 (1–3)
Duration of Wii Fit system ownership (months)	2.45 (0–12)	0	3.88 (0–12)	0	7.25 (1–12)
Average past practice with Wii Fit (h/week)	0.32 (0–3)	0	0.50 (0–3)	0	0.98 (0–3)

[*] See Table 1 for description of groupings. Values in parentheses are ranges unless otherwise indicated.
[**] A variety of sports were reported by the participants (no participant reported participating in recreational or competitive tennis, boxing, or skiing; 10 participants reported playing recreational soccer).

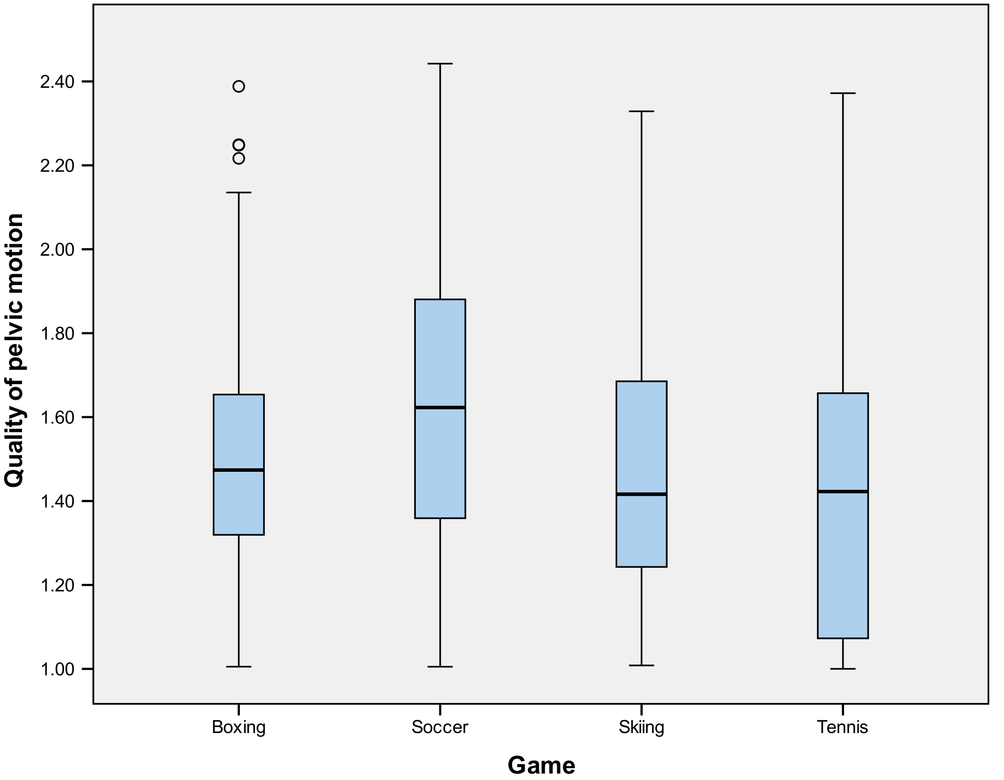


Fig. 2. Quality of movement (ALR, unitless) by game for all participants.

103) = 0.323, p = .571, Power = .087, and $F(1, 108)$ = 0.422, p = .517, Power = .099). For the Wii Fit soccer heading game, a main effect of experience on movement quantity was found ($F(1, 108)$ = 22.525, p < .001, Power = .999) with the experience group having a longer path length (all illustrated in Table 5 and Fig. 4). There was no effect of experience on ALR for this game ($F(1, 102)$ = 2.615, p = .109, Power = .360). For the Wii Fit ski slalom game, there was a main effect of experience on path length ($F(1, 108)$ = 8.912, p = .004, Power = .841), with the experienced group having a greater path length (see Table 5 and Fig. 5). There was a trend towards significance for a main effect of experience on ALR for this game ($F(1, 107)$ = 3.740, p = .056, Power = .483) as demonstrated by Fig. 6. The experience group had a trend towards smoother motion, with a lower ALR (see Table 5). There was no main effect of trial on any of the games, nor was there an interaction between trial and experience for any of the games.

3.4. Secondary analyses

The effect of motivation as a covariate on the relationship between experience and movement quantity and quality for both Wii Fit games (soccer heading and ski slalom) was evaluated. Motivation was not a significant covariate for either of these games.

4. Discussion

There is substantial interest in use of the Nintendo Wii Sports and Wii Fit virtual reality video games within rehabilitation interventions (Burdea et al., 2008; Deutsch et al., 2008; Halton, 2008).

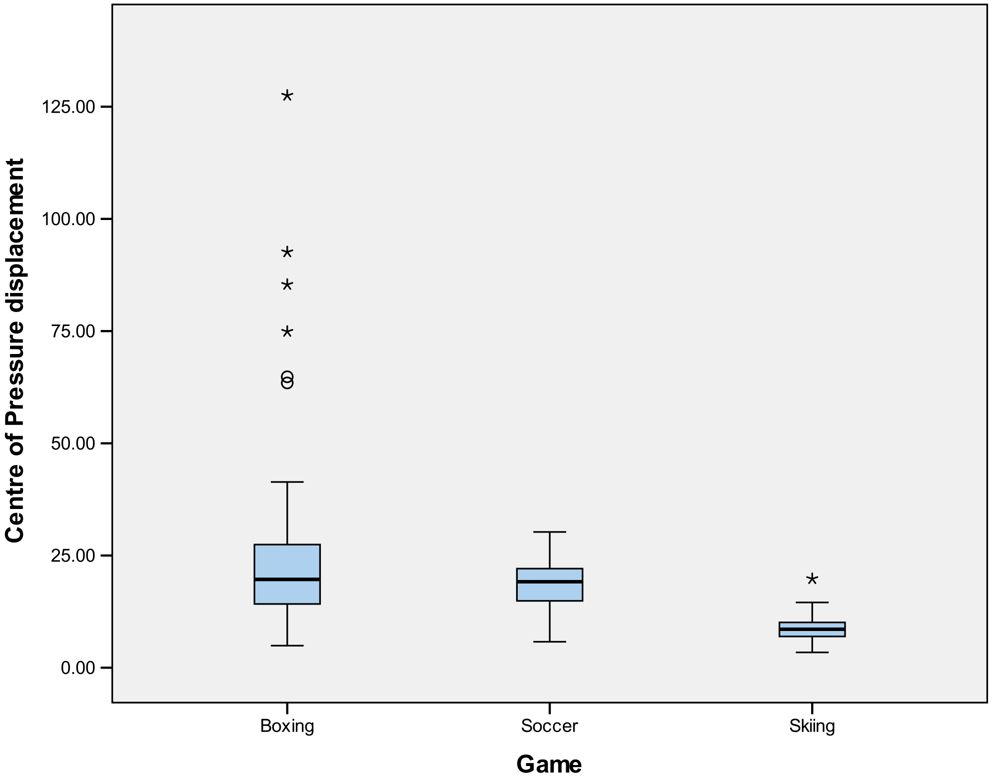


Fig. 3. Quantity of movement (center of pressure displacement, meters) by game for all participants.

Table 5
Quality and quantity of movement: means and standard deviations by game and experience level.

	ALR (unitless) Movement quality		Center of pressure displacement (meters) Movement quantity	
	Novice	Exp	Novice	Exp
Tennis	1.397 (.409) $p = .517$	1.440 (.298)	n/a	n/a
Boxing	1.532 (.347) $p = .571$	1.497 (.291)	20.825 (9.828) $p = .178$	25.503 (20.686)
Soccer Heading	1.583 (.414) $p = .109$	1.707 (.201)	17.488 (5.109) $p < .001$	22.251 (4.397)
Ski Slalom	1.540 (.352) $p = .056$	1.411 (.258)	8.225 (2.193) $p = .004$	9.639 (2.584)

An increased understanding of selected movement characteristics of game play in healthy children may support the development of research questions informing clinical decision-making with respect to use of these games in clinical situations. This study explores quantity and quality of movement in novice and experienced children playing four Nintendo Wii and Wii Fit games, and questions whether motivation to succeed at the game impacted these movement characteristics. Quantity of movement is defined as center of pressure path length displacement and quality of movement is defined as the ratio of curvilinear squared acceleration of the pelvis.

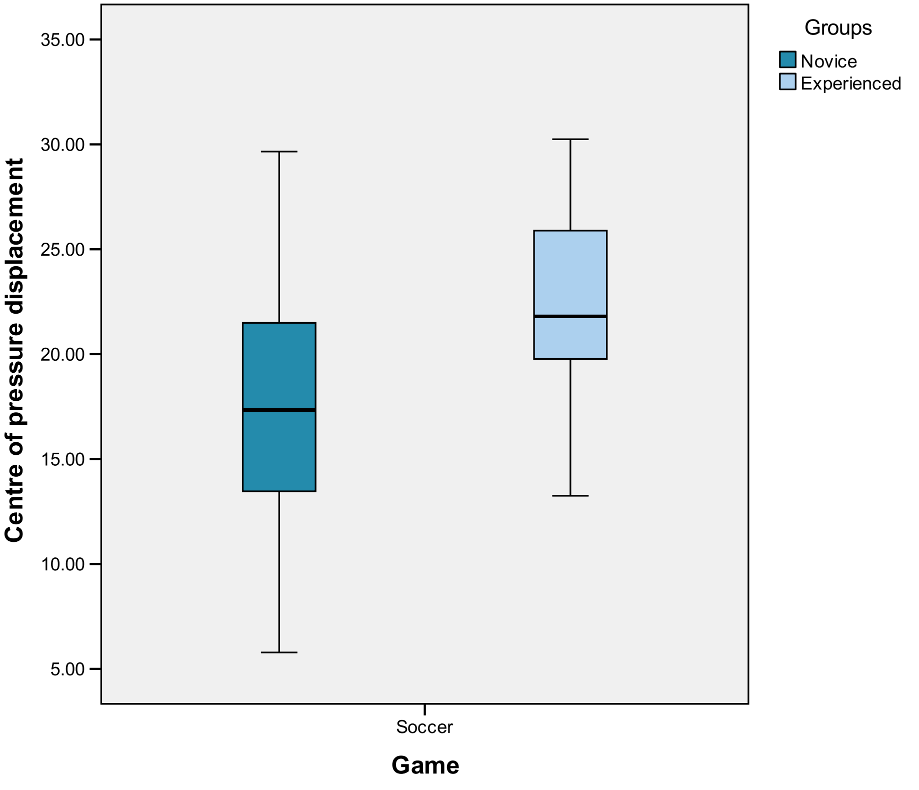


Fig. 4. Quantity of movement (center of pressure displacement, meters) by group for the Wii Fit soccer heading game.

4.1. Differences between games

Quantity and quality of movement during game play differed between the four games. Boxing, soccer heading, and skiing slalom differed significantly with respect to quantity of movement (quantity of movement during tennis play was not captured), while only soccer heading and tennis differed significantly with respect to quality of movement.

Center of pressure path length displacement represents motion of the body over its base of support. Children demonstrated this movement while playing each game. Boxing, the only game requiring bilateral upper extremity movement, elicited significantly greater movement quantity than did soccer heading or ski slalom, although it also demonstrated the most between-participant variability in this outcome. The finding that boxing resulted in greater center of pressure movement corresponds with the results of research by Graves, Ridgers, and Stratton (2008) who demonstrated that this game produced the highest energy expenditure in adolescents. Given that boxing game play elicits the most center of pressure movement, it may be appropriate to explore whether this game can be used to promote weight shifting abilities or dynamic balance in rehabilitation clients. However, researchers should consider that clinicians and families may perceive this game as violent and that this may impact decisions as to its use within therapy situations.

Although center of pressure displacement during Wii Fit game play is potentially more limited given that players must stand on the balance board, significant differences in movement quantity were found between the two Wii Fit games. Children demonstrated greater center of pressure displacement during soccer heading than during ski slalom game play. This finding may relate to game-specific differences in movement requirements or responses, and encourages further study of a wider variety of

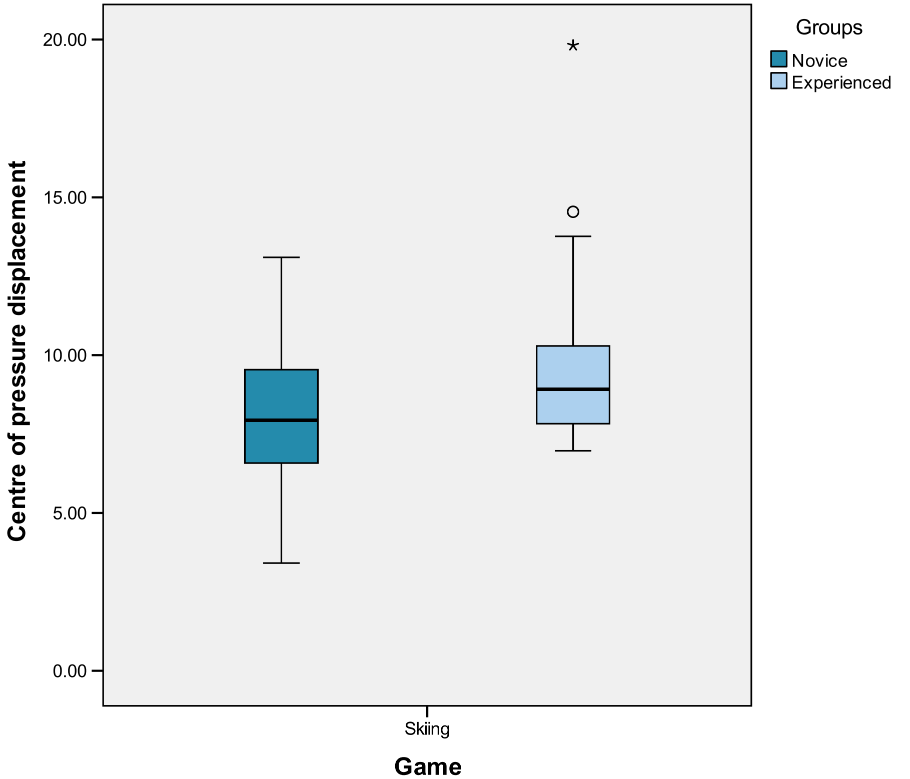


Fig. 5. Quantity of movement (center of pressure displacement, meters) by group for the Wii Fit ski slalom game.

Wii Fit games. Given that the soccer heading game does not require any upper extremity movement, it may be relevant to explore whether it can improve dynamic balance abilities in children for whom the addition of upper extremity tasks would be too challenging, or who may be tempted by a greater potential for "cheating" during boxing play.

This study demonstrated substantial between-participant variability in movement quality within each game. Although movement quality appeared to be least smooth (highest ALR) during soccer heading game play, the variability made it difficult to compare between games with respect to this outcome. From a clinical perspective, anecdotal observations during the study were of substantial variability in terms of the quality of children's movement during game play: from smooth, fluid motion to choppy movements. As an outcome, ALR reflects this observed variability. Subsequent research should employ a more comprehensive system of markers on different body segments to better discriminate segmental patterns of movement quality between games. The results of this study suggest that each of the four games elicits a wide range of movement strategies, from fluid to erratic. The potential use of these video games to enhance movement quality in rehabilitation clients requires exploration.

4.2. Differences between novice and experienced players

Game play experience does not significantly affect movement quantity (boxing: movement quantity was not measured during tennis game play) or quality (boxing or tennis) during Wii sport game play. Anecdotal observations were of substantial variability in movement characteristics between study participants, regardless of group. For example, some children demonstrated considerable movement of differing quality while playing tennis and boxing, while others, despite the standardized

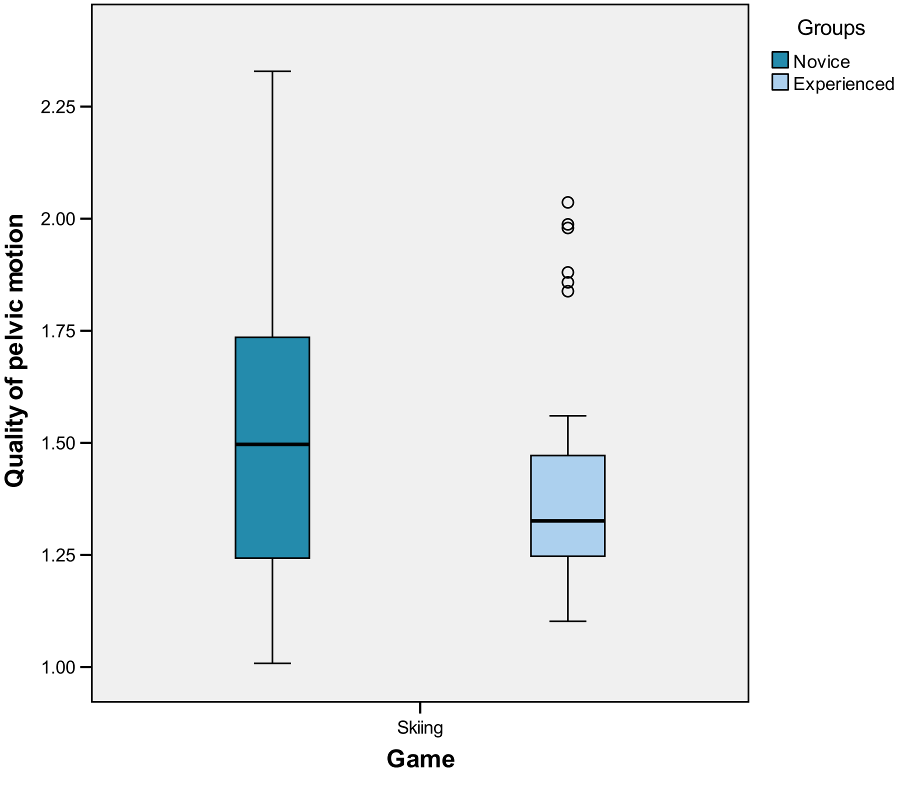


Fig. 6. Quality of movement (ALR, unitless) by group for the Wii Fit ski slalom game.

instructions, primarily manipulated the Wii remote. Given the lack of significant differences between groups, these findings provide preliminary indication that game experience alone is not a sole determinant of movement quantity or quality during game play. Although the variability between children within each group limits this interpretation, this information is relevant for further exploration of these games as unsupervised home-based interventions or with children who already have game play experience. Further research with respect to other potential factors that may impact children's movement characteristics during Wii game play is required.

Previous experience with the Wii Fit gaming system significantly affected movement quantity in both Wii Fit games. Children with Wii Fit experience demonstrated longer center of pressure path lengths. A longitudinal study of changes in movement quantity over time is required to confirm whether quantity of movement increases with game play experience. Children with game play experience may have a greater understanding of how to move on the balance board in order to achieve game success. Children without experience on these games were observed to move their head, trunk and/or upper extremities during game play rather than weight shift through their lower extremities.

Other factors relevant to the difference between groups include the fact that the standard instructions provided by the Wii Fit system may be misleading for novice players. The instructions state to "lean your body left and right" to control your avatar (Mii); this may not accurately convey to children the need to weight shift through their lower extremities. Additionally, a limitation of this study pertaining to the novice group was that the Mii avatar was created prior to the testing sessions, meaning that players did not perform the body test which is involved in setting up one's Mii. A portion of this test teaches the player how to effectively shift their weight on the balance board, putting novice players at a disadvantage with respect to learning the requirements of the game.

A trend towards significance was found between movement quality and experience for the ski slalom game. This game provides visual information, consistent across trials, about the upcoming gates to negotiate (see Table 1). Children with experience may have been better able to plan their movements in advance, resulting in smoother motion. In contrast, the soccer heading game does not give the player advance notice of the next presentation of the object to be headed, implying that players are not able to plan ahead regardless of their familiarity with the game. This may account for why movement quality was not significantly different between novice and experienced players for the soccer heading game.

Lastly, results of this study demonstrated that there was not an effect of trial in this study; i.e., that children did not show a trend towards a change in either outcome over the three trials. For novice players, three trials of the game did not appear to be sufficient to cause a learning effect with respect to change in movement characteristics. Further research to explore potential changes in movement characteristics over longer learning periods is required.

4.3. Effect of motivation

Motivation to succeed at the game did not affect the relationship between game play experience and movement quantity or quality. To the authors' knowledge, only one study has explored the relationship between motivation and movement strategies during game play, and changes in strategies were found based on motivation levels (Pasch et al., 2008). The psychometric properties of the question used to assess motivation in this study were not evaluated. Participants may not have understood the wording of the question or the rating scale used to assess their motivation. Motivation is a multidimensional construct; this study did not assess other facets of motivation unrelated to desire to achieve success at the game, nor did it attempt to relate movement characteristics to game success. Future studies assessing children's motivation while playing virtual reality games may benefit from using more detailed measures of this construct.

4.4. Additional research recommendations

The instructions provided in this study related to Wii Sport game play to "*move as if you were playing the games in real life*" (see Table 3) were intended to be consistent with the way in which therapists would use the games in their interventions. It is unlikely that therapists would allow their clients to cheat by simply moving the controller using wrist movement if their intent is to challenge and promote body movement. However, verbal instructions were repeated only once and the children were ultimately free to move as they desired. Some children in the study chose to perform only the minimum amount of movement required to be successful at the game. Allowing participants to choose their own movement strategies while playing the games (i.e., providing no additional cueing to change movement characteristics or to increase the amount of movement performed), may have enabled capture of a variety of movement characteristics which may be more reflective of how children would play the Wii games on their own without therapist supervision. Given that anecdotal observations were of substantial variability in movement characteristics, this may illustrate the need for a therapist to be present to instruct or cue the child to perform movements during game play in certain ways.

Indeed, these games were not designed for use in rehabilitation. Therapist role may be integral with respect to use of clinical and observational knowledge and skills to maximize the therapeutic value of this intervention. Study findings do not reflect the movement characteristics that could be achieved if children were to receive ongoing encouragement and instructions from a therapist to mimic real life actions or to focus on a certain element of movement. Further investigations exploring the role of the therapist during interventions involving these gaming systems are suggested.

Given the between-participant variability in this study, future studies investigating game play movement characteristics should explore the relationship between movement and factors such as age, gender, body mass index, real life sports experience/activity, and game success. The four games chosen for this study do not represent all the options provided by the Wii and Wii Fit platforms. Further study of a wider range of games is necessary to understand and quantify additional between-game differences as well as to determine whether between-platform (Wii versus Wii Fit) differences in movement characteristics exist as a whole.

4.5. Limitations

The age range of children in this study (7–12 years) may have contributed to the between-participant variability in the findings in that twelve year old children have had more experience with movement skills than have younger children. This study used convenience sampling; this may not represent the general population. All participants volunteered; therefore they may have been more motivated or interested in playing these games than the average child. Children were classified as either "novice", "Wii Sports experienced", or "Wii Sports and Wii Fit experienced" based on parent report. A range of length of ownership and average hours played per week was noted within the experienced groups. This heterogeneity may have affected study findings.

In order to record data while the children were playing the boxing game, movement had to be constrained to the area of the force plate. This may not be representative of how children would typically move during boxing game play and may have impacted our findings for this game. Quantity of movement during tennis game play could not be studied. The outcome measures used in this study did capture the full range of movement characteristics involved in game play. The use of more comprehensive motion-capture systems with full body marker systems would provide a more detailed analysis. Lastly, detailed logs of qualitative observations of children's movement characteristics during game play were not kept. Videotaping study participants for further qualitative movement analysis may have provided additional information to support study findings and afforded more support for anecdotal observations.

5. Conclusion

The Nintendo Wii and Wii Fit are accessible and appealing commercial virtual reality video gaming systems that are increasingly popular choices within pediatric rehabilitation due to their potential to challenge movement abilities. This study describes the potential active ingredients of quantity and quality of movement during game play in children (with and without game play experience) and evaluates whether these movement characteristics are influenced by player motivation to succeed at each game. Results of this study inform knowledge as to the movement requirements of these games and suggest directions for further research to inform clinical decision-making with respect to choice of games within pediatric rehabilitation interventions. Subsequent research will explore these movement characteristics of game play in children with neurological or developmental conditions. Overall, an increased understanding of these and other active ingredients of virtual reality video game play will support research evaluating the potential effectiveness of the Wii and Wii Fit as interventions to promote movement abilities in pediatric rehabilitation clients.

References

Burdea, G., Blois, T., Ching, E., Halton, J., Giratalla, M., Lopetinsky, B., et al. (2008). Nintendo Wii-based rehabilitation: Tutorial. In *Tutorial presented at the virtual rehabilitation 2008 conference*. Vancouver, BC.

Chen, Y. P., Kang, L. J., Chuang, T. Y., Doong, J. L., Lee, S. J., Tsai, M. W., et al. (2007). Use of virtual reality to improve upper-extremity control in children with cerebral palsy: A single-subject design. *Physical Therapy, 87*, 1441–1457.

Coyne, C. (2008). Video "games" in the clinic: PTs report early results. *PT – Magazine of Physical Therapy, 16*, 22–28.

Deutsch, J. E., Borbely, M., Filler, J., Huhn, K., & Guarrera-Bowlby, P. (2008). Use of a low-cost, commercially available gaming console (Wii) for rehabilitation of an adolescent with cerebral palsy. *Physical Therapy, 88*, 1–12.

Flynn, S., Palma, P., & Bender, A. (2007). Feasibility of using the Sony PlayStation 2 gaming platform for an individual post stroke: A case report. *Journal of Neurologic Physical Therapy, 31*, 180–189.

Graves, L. E. F., Ridgers, N., & Stratton, G. (2008). The contribution of upper limb and total body movement to adolescents' energy expenditure whilst playing Nintendo Wii. *European Journal of Applied Physiology, 104*, 617.

Halton, J. (2008). Tele-occupational therapy. Virtual rehabilitation with video games: A new frontier for occupational therapy. *Occupational Therapy Now, 10*, 12–14.

Jannink, M. J. A., van der Wilden, G. J., Navis, D. W., Visser, G., Gussinklo, J., & IJzerman, M. (2008). A low-cost video game applied for training of upper extremity function in children with cerebral palsy: A pilot study. *CyberPsychology and Behavior, 11*, 27–32.

LaViola, J. (2008). Bringing VR and spatial 3D interaction to the masses through video games. *IEEE Computer Graphics and Applications*(Sept/Oct), 10–15.
Nintendo Inc. (2009). Nintendo Wii Sports Resort. Retrieved August 6, 2009, from http://www.nintendo.ca/cgibin/usersite/display_info.cgi?pageNum=5&lang=en&id=5352161&from=wii.
Parsons, T. D., Rizzo, A. A., Rogers, S., & York, P. (2009). Virtual reality in pediatric rehabilitation: A review. *Developmental Neurorehabilitation, 12*, 224–228.
Pasch, M., Berthouze, N., van Dijk, B., & Nijholt, A. (2008) Motivations, strategies and movement patterns of video gamers playing Nintendo Wii boxing. In A. Nijholt & R. W. Poppe (Eds.). *Facial and bodily expressions for control and adaptation of games (ECAG 2008). CTIT Workshop proceedings, WP08-03* (pp. 27–33). Enschede, The Netherlands: Centre for Telematics and Information Technology, University of Twente.
Pierrynowski, M. R. (2009). Measurement properties of simple biomechanical measures of walking effort. *Computational and Mathematical Methods in Medicine, 10*, 219–228.
Rizzo, A., & Kim, G. J. (2005). A SWOT analysis of the field of virtual reality rehabilitation and therapy. *Presence: Teleoperators and Virtual Environments, 14*, 119–146.
Sandlund, M., McDonough, S., & Hager-Ross, C. (2009). Interactive computer play in rehabilitation of children with sensorimotor disorders: A systematic review. *Developmental Medicine and Child Neurology, 51*, 173–179.
Tanner, L. *Break a leg? Try "Wiihabilitation*". Retrieved June 7, 2009, from http://www.msnbc.msn.com/id/23070190.
The Associated Press. (2008). *'Wiihabilitation' – popular game benefits patients requiring physiotherapy*. Retrieved March 3, 2008, from http://news.therecord.com/Life/article/306331.
Weiss, P. L., Rand, D., Katz, N., & Kizony, R. (2004). Video capture virtual reality as a flexible and effective rehabilitation tool. *Journal of Neuroengineering and Rehabilitation, 1*, 12.
Whyte, J., & Hart, H. (2003). It's more than a black box; It's a Russian doll: Defining rehabilitation treatments. *American Journal of Physical Medicine and Rehabilitation, 82*, 639.
Zyga, L. (2007). *The healing power of Wii – interactive gaming is helping injured vets on the road to recovery*. Retrieved October 25, 2008, from http://www.pcmag.com/article2/0,2817,2170784,00.asp.