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Feasibility of Computer-Based Videogame Therapy for Children with Cerebral Palsy

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Abstract

Objectives: Standing and gait balance problems are common in children with cerebral palsy (CP), resulting in falls and injuries. Task-oriented exercises to strengthen and stretch muscles that shift the center of mass and change the base of support are effective in improving balance. Gaming environments can be challenging and fun, encouraging children to engage in exercises at home. The aims of this project were to demonstrate the technical feasibility, ease of use, appeal, and safety of a computer-based videogame program designed to improve balance in children with CP.
Materials and Methods: This study represents a close collaboration between computer design and clinical team members. The first two phases were performed in the laboratory, and the final phase was done in subjects' homes. The prototype balance game was developed using computer-based real-time three-dimensional programming that enabled the team to capture engineering data necessary to tune the system. Videogame modifications, including identifying compensatory movements, were made in an iterative fashion based on feedback from subjects and observations of clinical and software team members.
Results: Subjects ($n=14$) scored the game 21.5 out of 30 for ease of use and appeal, 4.0 out of 5 for enjoyment, and 3.5 on comprehension. There were no safety issues, and the games performed without technical flaws in final testing.
Conclusions: A computer-based videogame incorporating therapeutic movements to improve gait and balance in children with CP was appealing and feasible for home use. A follow-up study examining its effectiveness in improving balance in children with CP is recommended.

Introduction

Spastic cerebral palsy (CP) is one of the most common neurological disorders in children.[1] Standing and gait balance problems in spastic CP result from impaired muscle force production, limited joint range of motion, inappropriate muscle responses, muscle timing abnormalities, and inaccurate somatosensory processing in the lower extremities and trunk.[2–4] Thus, children with CP who have impaired standing and gait balance frequently lose their balance and fall and may experience injuries.[2] Because the majority of children with CP survive into adulthood, these deficits limit their ability to live independently and to participate in family, societal, and employment activities.[5]

Physical therapy (PT) treatment of children with CP typically involves interventions that target standing balance impairments and include practicing movement strategies that shift the center of mass relative to the base of support.[6,7] Compensatory trunk movements are discouraged during these weight-shifting exercises.[8,9] PT intervention systems use computerized force plate biofeedback to quantify the ability to shift the center of mass in various directions within the limits of stability during weight shifting.[7] These interventions improve speed of activation of muscle contractions and the ability to modulate muscle amplitude, thereby improving reactive standing balance.[10–12] The addition of visual feedback of directional displacements results in a more symmetrical walking pattern in these children.[13] However, the size and cost of these systems make them impractical for use in home-based PT exercise programs.

Videogaming with motion detection technology is increasingly used for rehabilitation. Studies in patients with

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CP,[14–16] traumatic brain injury,[17,18] stroke,[19–21] and Parkinson's disease[22,23] have shown successful motor rehabilitation using these interactive technologies. Computer-based videogames are hypothesized to be effective by creating engaging activities that motivate people to exercise.[24] This motivation theoretically improves compliance with home-based exercise programs.[25,26]

One of the benefits of videogames is that they can provide a progression of increasingly difficult challenges that help keep players engaged and motivated over extended periods of time. Challenges that are in the sweet spot between "too easy and therefore boring" and "hard and therefore frustrating" tend to maximize player engagement.[27] This "zone" in gaming is similar to the well-studied "zone of proximal development" in educational theory where learning occurs.[28,29] In rehabilitation, being in the "zone" fosters continued and mindful effort on the training goals. With a properly designed game, as players improve at one level of the game, they can move up to a more difficult level to maintain the proper amount of challenge, which in turn helps them stay engaged. When developing games for players with disabilities, designers must build in difficulty progressions that are appropriate for the abilities of the target audience. The lowest level of difficulty may be much easier than for a nonaffected player, and the variance between difficulty levels may be less, to provide appropriate step changes in difficulty for the targeted players.[30–32]

Commercially available videogames, such as the Nintendo Wii™ (Nintendo of America, Redmond, WA) are being used by children with CP as part of PT and have been shown to improve standing balance and gait.[33] These videogames are feasible for use in-home-based exercise PT programs given their portability, accessibility, and low cost.[34] However, "off-the-shelf" games are designed for the general public and do not address the specific needs of children with functional limitations. The movements are not based on therapeutic principles, and thus their therapeutic efficacy is limited.[34] In addition, neurorehabilitation usability studies have found that off-the-shelf games may actually provide negative auditory and visual feedback because patients are not fast enough or efficient enough to perform the movements required to play the game successfully.[35,36] Because of these user limitations, researchers are developing games specifically targeted for rehabilitation in particular populations.

The purposes of this project were to demonstrate the technical feasibility, ease of use, appeal, and safety of a computer-based videogame program using the Wii Fit™ Balance Board (Nintendo of America) in children with spastic CP. A game is a system in which players engage in an artificial conflict, defined by rules, that results in a quantifiable outcome.[37] In our game, the artificial conflict is the challenge of steering a paper airplane through a sequence of rings. Players control the airplane through their movements on the Wii Balance Board and Wiimote. The players receive points based on the number of rings they successfully steer the paper airplane through. A key aspect of maintaining player engagement during game play is to provide challenges that are appropriately matched to the player's ability.[38] In this game, the lowest difficulty level was designed so that most subjects would be able to complete the level. The highest difficulty level was designed to be moderately challenging to an unimpaired player. The intermediate difficulty levels were designed to provide challenges between these two end points and a smooth transition between levels. The game was designed as part of a home exercise program based on PT task-oriented interventions. The game required children to use movement strategies that shifted their center of mass relative to their base of support in standing without using compensatory lateral trunk flexion or rotation motions.[6,7]

Materials and Methods

This observational, cross-sectional feasibility and safety study incorporated a highly iterative design/evaluate/revise/re-evaluate process.

Participants

The institutional review boards at the University of California, San Francisco, San Francisco State University, and California Health and Human Services approved the project. Subjects were recruited from the California Children Services Medical Therapy Units in several counties in the San Francisco Bay area. Informed consent was obtained in writing from the subjects' parents, and verbal assent was given by the subjects. Fourteen subjects participated: four in the preliminary clinic evaluation and 10 in the in-home feasibility and safety testing. Inclusion criteria were as follows: diagnosis of spastic CP, good general health, cognitive function consistent with >7 years of age, able to follow a three-step command, Level I-III Gross Motor Function Classification System (GMFCS),[39] and independent household ambulation. Exclusion criteria were as follows: a seizure disorder that was not fully controlled and perceptual problems including visual or hearing impairments serious enough to interfere with the ability to understand the instructions or interact with the computer-based videogame.

Instruments and measurement

Sample characteristics. Demographic information was collected on all subjects to characterize the sample. Information pertaining to general health status, usual level of physical activity, fall history, CP disability level, and current PT program was obtained. The level on the GMFCS was determined. Standing and walking function were assessed by the Standing (subscale D) and Walking, Running, and Jumping (subscale E) of the Gross Motor Function Measure (GMFM)-66.[40] Reliability, validity, and responsiveness of the GMFM scores are well documented for children with CP.[41–43]

Intensity of physical activity. To determine subjective assessment of physical activity intensity during game play, the Borg Rating of Perceived Exertion Scale (RPE) was administered upon completion of the training trial.[44]

Safety, ease of use, and appeal. Safety was determined by the number of potential and actual falls that occurred during testing, and ease of use was assessed by a modified Short Feedback Questionnaire Pediatric Version (SFQP).[45] Subjects responded to the following questions by indicating stars on a Likert scale (for Questions 1–7, 1 star = not at all, 5 stars = very much; for Question 8, 1 star = very easy, 5 stars = very difficult):

1. How much did you enjoy playing the game?
2. How much did you feel you were a part of the game?
3. Did you feel you were good at the game?

4. How much did you feel in charge of what you were doing?
5. Did the game look and feel real?
6. Did you get enough information from the game to play?
7. Were you comfortable while you were playing?
8. How hard was it to play the game?

General procedures

The prototype game was developed using a computer-based real time three-dimensional programming platform that enabled the design team to capture engineering data necessary to customize the system. All stages of the project involved close collaboration between the game design and clinical team members. The collective project team decided that a virtual paper airplane game would elicit movement strategies necessary to maintain standing balance. The intended therapeutic movement was shifting weight from side to side, front to back, and diagonally at the pelvis and hips. Subjects controlled the movement of a virtual paper airplane by shifting weight in different directions on the Nintendo Wii Fit Balance Board to guide the plane toward a series of targets (Fig. 1). The positions of the targets were set to elicit the therapeutic motions that the project team had specified for the game.

Iterative design/evaluate/revise/evaluate procedure

During the early formative evaluation stages, the prototype was modified after each successive evaluation. Preliminary evaluations occurred at two clinics where subjects were informed that the software, and not the child's performance, was being evaluated. A gait belt was secured around the child's waist. The subject then moved onto the Wii Fit Balance Board and held a Wii Motion Plus™ controller (Nintendo of America) on his or her chest to detect trunk leaning. For Subject 2, the Wii Motion Plus controller was attached to the subject's chest with a strap. Project team members stood on either one or both sides of the subject, within easy reach to prevent a fall. While the subject played the videogame, the project evaluator would query the subject's "in-process" thoughts. Opportunities were provided for the subject to rest if needed. When subjects no longer wanted to play the games or a 40-minute time was reached (whichever came first), the subject moved to a different part of the room, and the Borg RPE and the SFQP assessments were administered. The evaluation sessions were recorded on video for later review by team members. Based on the observation of the first two subjects, the project team decided to detect and provide feedback to subjects about undesired, compensatory movements of trunk lateral flexion and rotation that physical therapists discourage during weight-shifting exercises in standing for children with CP.[8,9] The Wii Motion Plus controller detected these compensatory movements, and the videogame was modified for the next preliminary evaluation to provide immediate feedback to the player by changing the virtual plane's color from green to red.

FIG. 1. Screen shot of the videogame. The player flew the airplane by weight-shifting in a standing position to move through the rings. The outermost ring awarded lowest points; the center star awarded the highest point score. Audio feedback was a positive chime for points, crashing sound for hitting the outside rim, and no sound effect for missing the target all together. Color graphics available online at www.liebertonline.com/g4h

Preliminary evaluation

Four subjects participated sequentially in this phase of the game development. Team members held review meetings after each subject played, and additional tasks and refinements were incorporated into the prototype game. These refinements were implemented, and the prototype was thoroughly tested and debugged in preparation for the final evaluation.

Final evaluation of the prototype

In total, 10 subjects were recruited from an expanded geographic area of California Children Services Medical Therapy Units in several counties in the San Francisco Bay area. The prototype game was not changed during this phase of evaluation to allow for aggregate analyses. Data were collected in the subject's homes to assess feasibility and safety in the intended user environment.

The final testing procedure did not differ from the preliminary evaluations except for the following: (1) Subjects were fitted with the Wii Motion Plus front pack on their chest. (2) One clinical team member demonstrated with one subject the correct movements for shifting weight over the hip that resulted in a green color for the plane and the incorrect, compensatory movements of trunk lateral flexion and rotation that changed the color of the plane to red. (3) The movement detection/feedback system was turned on and off for this subject to determine its effectiveness. The subjects held a Wiimote in the center of their chest, pointed vertically, to allow the researchers to detect if and/or when the subject leaned over at their waist while performing the game. If the subject's lean was more than 20° from vertical, this was recorded as "subject leaning," which indicated that the subject was attempting to compensate while trying to steer the plane (instead of standing up straight and shift his or her weight with the hips).

Results

Preliminary results

The results from the evaluations of the early version of the prototype showed that the games performed well with only

Table 1. Preliminary Clinic Evaluations of Subjects' Testing Results and Game Modifications

Subject	*Outcome*	*Observations*	*Post-modifications*
11-year-old boy with spastic diplegia: GMFCS level II; GMFM Subscale D, 34; GMFM Subscale E 59	Enjoyment: 5 Control: 5 Difficulty: 2 Safety: No falls	Subject did not move plane far enough to either side to hit all targets. Holding Wii Motion Plus controller in his hand was difficult.	Changed introduction to include verbal instruction to move plane all the way to each side during tutorial. Changed procedure by securing Wii Motion Plus controller inside gait belt
9-year-old boy with spastic diplegia: GMFCS level III; GMFM Subscale D, 30; GMFM Subscale E, 38	Enjoyment: 3 Control: 5 Difficulty: 5 Safety: No falls	Subject responded well to instructions, maintained weight shift longer, and was able to reach more distant targets. Subject needed to hold walker during game and could not hold Wii Motion Plus controller because of his physical impairments.	Modified tutorial narration to include instruction to move plane all the way to each side. Changed tutorial to focus on this step. Created less difficult initial levels. Created chest "strap" that subject would wear to hold Wii Motion Plus controller in place
8-year-old girl with hemiplegia: GMFCS level I; GMFM Subscale D, 38; GMFM Subscale E, 68	Enjoyment: 5 Control: 5 Difficulty: 5 Safety: No falls	Although the subject rated the game as "very, very difficult," she also indicated that she enjoyed it very much—supporting the basic contention that game players like a tough challenge.	Added data tracking to capture additional trunk motion and feedback data
9-year-old boy with spastic diplegia: GMFCS level I; GMFM Subscale D, 38; GMFM Subscale E, 65	Enjoyment: 4 Control: 5 Difficulty: 2 Safety: No falls	Subject previously rejected PT exercises but was engrossed in the videogames.	Tracked compensatory movements and provided visual feedback

GMFCS, Gross Motor Function Classification System levels I–V (where a lower score indicates higher function); GMFM, Gross Motor Function Measure, with two subscales—Subscale D for standing (39 possible) and Subscale E for running and jumping (72 possible) (where a higher score indicates higher function); PT, physical therapy.

minor bugs. The detection of trunk lateral flexion and rotation compensatory motions was added and successfully tested. The four subjects were very interested in playing the game and rated it very highly. The results of each preliminary evaluation, prototype modifications, and subjects' characteristics are shown in Table 1.

Home testing results

Table 2 describes the 10 subjects' individual characteristics, including age (average, 9.8 ± 1.2 years), gender (five boys and five girls), GMFCS level (eight at level I and two at level II), CP diagnosis (five hemiplegia and five diplegia), GMFM subscale D score (average, 34.70 ± 3.40), and GMFM subscale E score (average, 63.8 ± 6.97). Table 3 lists the median scores for items on the SFQP and the Borg RPE. Subjects were able to play the games safely; no falls occurred during the testing. Figure 2 shows the results for one subject when the motion detection/feedback system was turned on and off. The provision of feedback resulted in decreased compensatory trunk movements (lateral flexion and rotation).

Table 2. Subjects' Characteristics for Home Evaluations

				GMFM subscale	
Age (years)	*Gender*	*GMFCS level (I–V)*	*Diagnosis*	*D (39 total)*	*E (72 total)*
8	Male	I	Right hemiplegia	39	65
9	Female	I	Spastic diplegia with dystonia	36	63
9	Male	I	Spastic diplegia	37	70
10	Female	I	Right hemiplegia with dystonia	36	72
9	Female	I	Right hemiplegia	33	66
11	Female	I	Right hemiplegia	37	68
12	Male	II	Spastic diplegia	30	55
11	Female	I	Left hemiplegia	36	67
9	Male	I	Spastic diplegia	35	63
10	Male	II	Spastic diplegia	28	49

GMFCS, Gross Motor Function Classification System levels I–V (where a lower score indicates higher function); GMFM, Gross Motor Function Measure, with two subscales—Subscale D for standing (39 possible) and Subscale E for running and jumping (72 possible) (where a higher score indicates higher function).

Table 3. Home Evaluation Median and Range for the Subjective Measures

Measure	*Median score*	*Min–Max*
Short Feedback Questionnaire, Pediatric Version (modified)		
Enjoy playing games (from 1 = not at all to 5 = very much)	4.5	1–5
Feels part of game (from 1 = not at all to 5 = very much)	4.5	2–5
Feels was good at game (from 1 = not at all to 5 = very much)	5.0	1–5
Feels in charge (from 1 = not at all to 5 = very much)	4.0	2–5
Game looked and felt real (from 1 = not at all to 5 = very much)	5.0	1–5
Get enough information to play (from 1 = not at all, 5 = very much)	5.0	1–5
Comfortable playing (from 1 = not at all to 5 = very much)	3.0	1–5
How hard to play (from 1 = very difficult to 5 = very easy)	3.0	1–5
Total score (total possible score 40)	31.5	17–37
Borg Rating of Perceived Exertion Scale (from 1 = very light to 10 = very, very hard exertion)	5.0	1–10

Min–Max, minimum–maximum range.

Discussion

No safety issues were encountered in any of the clinic or home evaluations of subjects. Limited exertion was reported after playing the videogame. These results can be attributed to the close collaboration between the project team members that produced games suitable for the target audience that did not foster unsafe situations or elicit overexertion.

The finding that the videogame was very appealing to the subjects was consistent with other research showing that children with CP enjoyed playing therapeutic videogames and preferred them over more conventional home-based exercise programs developed by physical therapists.[26] Therapeutic videogames are very engaging and motivate children to participate when the physical therapist is not present to encourage them.[24] The use of videogames for therapy in home-based programs may increase exercise compliance.[25,26] More frequent use of therapeutic videogames, compared with engagement in traditional PT, at home may improve standing and gait balance in children with CP because of the increased amount of practice time.[7]

This therapeutic videogame was specifically designed for children with spastic CP who have slow and limited movement ability and often demonstrate compensatory motions not seen in normal children.[2–4] Commercially available videogames that are not adapted for these functional limitations may prevent children from being successful in playing the games. This videogame allowed the subjects to be successful in manipulating the airplane by using therapeutic movements to reach the target and score points. Extrinsic and augmented feedback increased success. Successful results evident in the number of scored points may lead to improved motivation to continue practicing this type of PT home exercise program.[43]

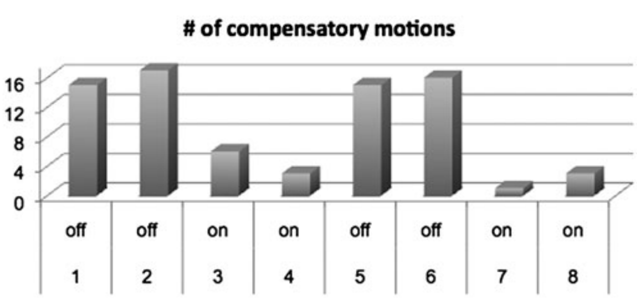

FIG. 2. Results for one subject when the motion detection-feedback system was turned on and off as the player attempted different, equivalent versions of the game. When the subject executed undesired movements, the system detected the movements and provided the subject with feedback that enabled him to reduce the number of undesired movements. The graph illustrates that when feedback was turned on (levels 3, 4, 7, and 8), the subject dramatically decreased the amount of undesired movement. When the feedback was turned off (levels 1, 2, 5, and 6), the amount of undesired movement was much higher.

The game also provided another form of extrinsic or augmented feedback called knowledge of performance by indicating when the correct movement pattern was being used to reach the targets.[43] When subjects performed compensatory lateral trunk flexion and rotation movements, the system detected them and provided accurate and helpful feedback, and subjects reduced the number of compensatory trunk movements based on the feedback. These types of abnormal movements would be discouraged during in-person PT interventions.[8,9] Therapeutic videogames that provide feedback on compensatory movements are beneficial for home-based standing balance training programs where physical therapists are not available to guide motions or provide verbal feedback on knowledge of performance.

The study's sample was limited to less physically impaired children with CP because of difficulty in recruiting subjects with a GMFCS level III. Most children had a GMFCS level I and high GMFM scores, ambulated without assistive devices, and performed gross motor skills with decreased speed, balance, and coordination. One subject from the preliminary evaluation with a GMFCS level III ambulated with a walker. Future studies using this videogame and Wii Fit Balance Board need to examine its feasibility as a home-based exercise program with subjects who have more physical impairments, higher GMFCS levels, and lower GMFM scores. Children with CP who are more physically impaired may be at more risk for falls and demonstrate more decreased standing and walking function and compensatory trunk movements when using the videogame.

This feasibility study was not designed to determine if using the videogame resulted in improved function. Future research is needed to measure the effectiveness of this home-based exercise program on improving standing and gait balance in children with CP. The study also did not examine the effects of different feedback schedules on performance of the videogame. Future studies should determine which type of feedback schedule using this videogame results in improved standing and walking balance in children with CP.

A computer-based videogame using the Wii Fit Balance Board that incorporated therapeutic movements to improve standing and gait balance in children with CP was safe, appealing, and feasible for home use. A follow-up study examining its effectiveness as a home-based exercise program in improving standing and gait balance in children with CP is recommended.

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Author Disclosure Statement

No competing financial interests exist.

References

1. Winter S, Autry A, Boyle C, Yeargin-Allsopp M. Trends in the prevalence of cerebral palsy in a population-based study. Pediatrics 2002; 110:1220–1225.
2. Burtner PA, Woollacott MH, Craft GL, Roncesvalles MN. The capacity to adapt to changing balance threats: A comparison of children with cerebral palsy and typically developing children. Dev Neurorehabil 2007; 10:249–260.
3. Donker SF, Ledebt N, Roerdink M, et al. Children with cerebral palsy exhibit greater and more regular postural sway than typically developing children. Exp Brain Res 2008; 184:363–370.
4. Lowes L, Westcott S, Palisano R, et al. Muscle force and range of motion as predictors of standing balance in children with cerebral palsy. Phys Occup Ther Pediatr 2004; 24:57–77.
5. van der Dussen L, Nieuwstraten W, Roebroeck M, Stam HJ. Functional level of young adults with cerebral palsy. Clin Rehabil 2001; 15:84–91.
6. Harris SR, Roxborough L. Efficacy and effectiveness of physical therapy in enhancing postural control in children with cerebral palsy. Neural Plasticity 2005; 12:229–243.
7. Shumway-Cook A, Woollacott M. *Motor Control: Translating Research into Clinical Practice.* Philadelphia: Lippincott, Williams and Wilkins; 2012.
8. Bly L, Whiteside A. *Facilitation Techniques Based on NDT Principles.* Austin, TX: Pro-Ed; 1997.
9. Stamer M. *Posture and Movement of the Child with Cerebral Palsy.* San Antonio, TX: Pearson Education Inc.; 2000.
10. Shumway-Cook A, Hutchinson S, Kartin D, et al. Effect of balance training on recovery of stability in children with cerebral palsy. Dev Med Child Neurol 2003; 45:591–602.
11. Woollacott MH, Shumway-Cook A. Postural dysfunction during standing and walking in children with cerebral palsy: What are the underlying problems and what new therapies might improve balance? Neural Plasticity 2005; 12:211–219.
12. Woollacott MH, Shumway-Cook A, Hutchinson, et al. Effect of balance training on muscle activity used in recovery of stability in children with cerebral palsy: A pilot study. Dev Med Child Neurol 2005; 47:455–461.
13. Ledebt A, Becher J, Kapper J, et al. Balance training with visual feedback in children with hemiplegic cerebral palsy: Effect on stance and gait. Motor Control 2005; 9:459–468.
14. Howcroft J, Klejman S, Fehlings D, et al. Active video game play in children with cerebral palsy: Potential for physical activity promotion and rehabilitation therapies. Arch Phys Med Rehabil 2012; 93:1448–1456.
15. Sandlund M, McDonough S, Hager-Ross C. Interactive computer play in rehabilitation of children with sensorimotor disorders: A systematic review. Dev Med Child Neurol 2009; 51:173–179.
16. Brien M, Sveistrup H. An intensive virtual reality program improves functional balance and mobility of adolescents with cerebral palsy. Pediatr Phys Ther 2011; 23:258–266.
17. Gil-Gómez JA, Lloréns R, Alcañiz M, Colomer C. Effectiveness of a Wii balance board-based system (eBaViR) for balance rehabilitation: A pilot randomized clinical trial in patients with acquired brain injury. J Neuroeng Rehabil 2011; 8:30.
18. Ustinova KI, Leonard WA, Cassavaugh ND, Ingersoll CD. Development of a 3D immersive videogame to improve arm-postural coordination in patients with TBI. J Neuroeng Rehabil 2011; 8:61.
19. Bisson E, Contant B, Sveistrup H, Lajoie Y. Functional balance and dual-task reaction times in older adults are improved by virtual reality and biofeedback training. Cyberpsychol Behav 2007; 10:16–23.
20. Boian R, Sharma A, Han C, et al. Virtual reality-based post-stroke hand rehabilitation. Stud Health Technol Inform 2002; 85:64–70.
21. Holden MK, Dyar TA, Schwamm L, Bizzi E. Virtual-environment-based telerehabilitation in patients with stroke. Presence 2005; 14:214–233.
22. Weghorst S. Augmented reality and Parkinson's disease. Commun ACM 1997; (Aug):47–48.
23. Esculier JF, Vaudrin J, Beriault P, et al. Home-based balance training programme using Wii Fit with balance board for Parkinsons's disease: A pilot study. J Rehabil Med 2012; 44:144–150.
24. Sandlund M, Waterworth EL, Hager C. Using motion interactive games to promote physical activity and enhance motor performance in children with cerebral palsy. Dev Neurorehabil 2011; 14:15–21.
25. Harris K, Reid D. The influence of virtual reality play on children's motivation. Can J Occup Ther 2005; 72:21–29.
26. Bryanton C, Bosse J, Brien M, et al. Feasibility, motivation, and selective motor control: Virtual reality compared to conventional home exercise in children with cerebral palsy. Cyberpsychol Behav 2006; 9:123–128.
27. Hawkings T, ed. *Video Game Design Fundamentals.* Los Angeles: Electronic Entertainment Expo; 1995.
28. Vygotsky LS. *Mind and Society: The Development of Higher Psychological Processes.* Cambridge, MA: Harvard University Press; 1978.
29. Chaiklin S. The zone of proximal development in Vygotsky's analysis of learning and instruction. In: Kozulin A, Gindis B, Ageyev V, Miller S, eds. *Vygotsky's Educational Theory and Practice in Cultural Context*. Cambridge, MA: Cambridge University Press; 2003.
30. Pagulayan RJ, Keeker K, Wixon D, et al. User-centered design in games. Hum Comput Interact Handbook 2002; 28:883–906.
31. Medlock MC, Wixon D, Terrano M, et al. Using the RITE method to improve products: A definition and case study.

Bloomingdale, IL: Usability Professionals Association, 2002.
32. Fulton B, Medlock M. Beyond focus groups: Getting more useful feedback from consumers. Presented at the Game Develop Conference, Santa Clara, CA, 2003.
33. Deutsch JE, Borbely M, Filler J, et al. Use of a low-cost, commercially available gaming console (Wii) for rehabilitation of an adolescent with cerebral palsy. Phys Ther 2008; 88:1196–1207.
34. Levac D, Pierrynowski MR, Canestraro M, et al. Exploring children's movement characteristics during virtual reality video game play. Hum Mov Sci 2010; 29:1023–1038.
35. Lange BS, Flynn SM, Rizzo AA. Initial usability assessment of the off-the-shelf video game consoles for clinical game-based motor rehabilitation. Phys Ther Rev 2009; 14:355–363.
36. Lange B, Flynn S, Proffitt R, et al. Development of an interactive game-based rehabilitation tool for dynamic balance training. Top Stroke Rehabil 2010; 17:345–352.
37. Salen K, Zimmerman E. *Rules of Play: Game Design Fundamentals.* Cambridge, MA: MIT Press; 2003.
38. Prensky, M. *Digital Game-Based Learning*. New York: McGraw-Hill; 2003.
39. Palisano R, Rosenbaum P, Bartlett D, Livingston M. *Gross Motor Function Classification System—Expanded and Revised.* Hamilton, ON, Canada: CanChild Centre for Childhood Disability Research, McMaster University; 2007.
40. Russell DJ, Rosenbaum PL, Avery LM, Lane M. *Gross Motor Function Measure (GMFM-66 & GMFM-88) User's Manual: Clinics in Developmental Medicine, No. 159*. London: Mac Keith Press, 2002.
41. Russell DJ, Avery LM, Rosenbaum PL, et al. Improved scaling of the Gross Motor Function Measure for children with cerebral palsy: Evidence of reliability and validity. Phys Ther 2000; 80:873–885.
42. Wang HY, Yang YH. Evaluating the responsiveness of 2 versions of the Gross Motor Function Measure for children with cerebral palsy. Arch Phys Med Rehabil 2006; 87:51–56.
43. Borg GA. Perceived exertion: A note on "history" and methods. Med Sci Sports 1973; 5:90–93.
44. Kizony R, Katz N, Rand D, Weiss PLT. Short Feedback Questionnaire (SFQ) to enhance client-centered participation in virtual environments. Cyberpsychol Behav 2006; 9:687–688.
45. Schmidt RA, Lee TD. *Motor Control and Learning: A Behavioral Emphasis*, 5th ed. Champaign, IL: Human Kinetics; 2011.

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