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Use of Active Video Gaming in Children with Neromotor Dysfunction: A Systematic Review

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USE OF ACTIVE VIDEO GAMING IN CHILDREN WITH NEUROMOTOR DYSFUNCTION: A SYSTEMATIC REVIEW

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ABSTRACT

Background and Purpose: Active video games (AVG) are gaining popularity as a strategy for improving motor function in children with neurologically-based movement disorders, but there is no consensus regarding AVG's utility or effectiveness in this population. The purpose of this systematic review was to examine current evidence on the use of AVG to improve motor function in children 2-17 years of age with neurologically-based movement disorders.

Methods: Authors followed standard criteria for systematic review conduct and rating quality of evidence including the PRISMA checklist. Databases searched were Scopus, MEDLINE, Cochrane Library, EMBASE, and CINAHL. Systematic reviews, randomized control trials, or longitudinal studies were included if they investigated AVG for improving movement-related outcomes in children aged 2-17 years with neurologically-based movement disorders. Parameters studied included: health condition, strength of evidence, delivery methods or systems for AVG, capacity for adjusting to individual needs and skill levels, outcomes addressed with AVG, effectiveness for achieving targeted outcomes [primarily activity-level motor outcomes (n=36)], and challenges/limitations.

Results: The 20 articles included in the review varied in quality from high (n=6), to moderate (n=4) to low (n=8) with two strong quality single subject research design (SSRD) studies. Studies involved children with 6 neurologic conditions using AVG in clinical, home or school settings for 49 different outcomes. Frequency and duration of dosage varied. Choice of games played and difficulty level were controlled by therapists (n=6) or the child (n=14). The most commonly reported limitations were small sample sizes and difficulty providing task-specific practice of functional movements via AVG. All studies reported improvement with AVG, though differences were not consistently significant compared to traditional therapy.

Discussion: Heterogeneity of measurement tools and target outcomes prevented meta-analysis or development of formal recommendations. However, AVG has demonstrated feasibility and shows potential for improving activity-level outcomes (including those assessing balance, gross motor function, and upper and lower limb function) of children with neuromotor disorders, and should be considered when developing plans of care for this population. Additional research with larger samples, and investigations that explore dosing variables and utility for extending practice by home programming are merited.

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INTRODUCTION

Neurological conditions are among the most common, complex, and costly diagnoses contributing to childhood disability, and have potential to affect the health, wellness, growth, and development of affected children throughout their lifespan.[1,2] Examples of the range of disorders associated with lifelong disability include cerebral palsy (CP), autism spectrum disorder, developmental coordination disorder (DCD), Down syndrome, epilepsy, brain injury, and fetal alcohol syndrome. Of these, autism is the most common neurological condition affecting children (15.5 in 1000),[3] while CP is the most common cause of permanent motor disability (affecting three to four in 1000 children).[4] Although specific signs and symptoms vary, primary impairments of body structure and function seen in lifelong neurological conditions affect the functions of brain, muscle, and bone. As children age, these impairments increase the risk of limitations in major life activities such as walking or talking as well as participation in family and community life. Individuals with such conditions additionally tend to be less active than the general population, so they may also develop secondary conditions such as poor cardiopulmonary function, obesity, decreased bone mineral density, and generalized muscular weakness.[5] These comorbidities put them at greater risk for chronic diseases such as diabetes, asthma, hypertension, stroke, and arthritis across the lifespan.[6,7]

A common challenge among children with these conditions is delayed or disordered motor development, which affects a child's development across domains. Perceptual–motor experiences allow a child to participate and function in every moment, and are integral to cognitive development.[8,9] In children with CP, a lower level of fine motor skills is a precursor to delayed development of numeracy.[10] Children with DCD exhibit delays in social and emotional development, seen in their lower self-worth, higher levels of anxiety, and the perception of themselves as being less competent and having less social support.[11]

The health and developmental consequences of growing up with childhood-onset neurological conditions are undoubtedly severe, but the consequences to the families caring for these children are also extremely high. The caregiver burden includes negative effects on finances, family stress, physical and mental health, family functioning, and social interaction.[12] An Indian study of 207 caregivers showed that almost half of the families were below the poverty line, while more than two-thirds of the families had mild to severe depression and more than two-thirds had mild to severe anxiety.[13] With such prevalent and pervasive impacts, identifying the most effective interventions for these neuromotor conditions is critical to improving the well-being of all involved.

There are currently a wide range of strategies being used to address the motor issues associated with lifelong neurological conditions, such as hippotherapy, constraint-induced movement strategies, and sensory processing techniques. No matter the strategy used, researchers have identified three important components known to drive neuroplastic brain changes and improve functional outcomes in individuals with neuromotor conditions: practice must be task-specific, delivered at a high volume, and directed towards goals that are meaningful for the child and family.[14–16]

While therapists have become skilled at incorporating meaningful, task-specific practice into their plans of care, they struggle to achieve high-volume practice both during and outside therapy sessions.[17] Although regular home-exercise programs, involving children and their caregivers, are seen as a crucial part of achieving the volume of practice necessary to drive change,[18,19] these programs can easily become ‘chores’ that challenge the motivation of children and parents to sustain these activities over time.[15] A study of caregivers of children with disabilities showed that 66% of the caregivers were non-compliant with the home exercise programs.[20]

One solution to the challenge of using home programs to boosting volume of practice is to embed practice of functional tasks into existing daily routines. For children, daily routines often include video games, with play times for children averaging 1.25 hours per day.[21] Furthermore, 94% of American school-aged children were reported to have played some form of electronic game in the previous 6 months.[22] In this context, the recent trend towards incorporating active video gaming (AVG) into therapeutic plans of care and home activity programs makes sense. There has been an unprecedented increase in gaming technologies that could potentially serve as rehabilitation tools. Examples of AVG products available include EyeToy for Sony PlayStation 2, PlayStation 3 Move, Nintendo Wii/Wii-U, Kinect for Microsoft's Xbox 360/Xbox One, dance mats, etc., which require the users to move various limbs or their entire bodies to play the games.[23]

Use of AVG technology in children with neurological conditions is gaining popularity; however, evidence for its efficacy as a therapeutic intervention is inconsistent.[24] Hammond et al. reported significant improvement in motor skills with AVG training,[25] while Ferguson et al. and Smits-Engelman et al. found neuromotor task training to be more effective in improving motor proficiency than AVG.[26,27] Current systematic reviews have focused on AVG as a method of addressing obesity and general physical health in children and adults, as well as identifying specific conditions, primarily of adults, in which AVG might be effective.[28] The two existing systematic reviews that have evaluated AVG as a motor skill therapy had a narrow focus on children with CP and included studies that constituted low-level evidence and used non-commercially available AVG. Currently, no clear recommendations as a motor intervention are available to assist clinicians, families, and other stakeholders in making decisions about the use of AVG.

Thus the purpose of this study is to systematically review evidence about the use of AVG as a therapeutic intervention for improving motor outcomes in children with neuromotor conditions. Specifically, the following parameters will be examined: health conditions in which AVG has been used, strength of the available evidence, delivery methods or systems for AVG, capacity for adjusting to individual needs and skill levels, effectiveness for achieving outcomes, and challenges/limitations in researching AVG. Bringing together the evidence on these parameters will assist practitioners, patients, and families in making decisions about how and when to incorporate AVG designed to improve functional movement into physical therapy plans of care for children with movement disorders. This information will assist in the design of future therapeutic technologies for this population.

METHODS

This systematic review was completed in accordance with the American Academy for Cerebral Palsy and Developmental Medicine (AACPDM) methodology,[29,30] and the PRISMA checklist for systematic reviews.[31] The study was also registered with the PROSPERO international prospective register of systematic reviews (registration number CRD42015029147).[32]

Studies included in this review investigated commercially available AVG used for improving movement-related outcomes across all levels of the International Classification of Functioning, Disability and Health (ICF) in children aged 2 to 17 years with neuromotor disorders affecting movement. The focus on commercially available systems, widely accessible to clinicians, was made in an attempt to maximize the usefulness of this review. Studies classified as systematic reviews, randomized control trials, and longitudinal studies were included in this analysis.

Databases searched included Scopus, MEDLINE, Cochrane Library, EMBASE, and CINAHL, as recommended by the AACPDM.[29] Search terms were developed with the guidance of the health and life sciences librarian at the affiliated institution and included the following terms: [(Active video games) OR (interactive video games) OR (exergames) OR (video games)] AND [(physical therapy) OR (rehabilitation) OR (cerebral palsy) OR (autism) OR (brain injury) OR (developmental coordination disorder) OR (down syndrome) OR (epilepsy) OR (fetal alcohol syndrome) OR (neuromuscular disease) OR (neurodevelopmental disorder) OR (movement disorder)].

The term 'virtual reality,' although often used to refer to commercially available systems, was not included as a search term in an effort to exclude articles studying the developing technology of true 'virtual reality', in which the user is immersed in a computer-generated, full three-dimensional environment. Virtual reality/augmented reality are new avenues that can and should be examined in the future, as new commercial products are now on the market, for example Oculus Rift, HTC Vive, PlayStation VR, Samsung Gear VR, Google Cardboard. However, it should be noted that the virtual reality systems vary greatly in terms cost, equipment, environment, and experience. This variability currently makes ‘commercial’ virtual reality very difficult to assess; thus, we excluded systems described as virtual reality from our study. We believe our chosen terms offered enough redundancy to access all studies researching commercially available AVG. Filters used included English language only, participant age range 2 to 17 years, and publication date between January 2005 and December 2015. Once articles were retrieved, their references were reviewed for additional relevant literature. Two reviewers (LP and RM) independently determined inclusion eligibility for each article. In cases where consensus between reviewers could not be reached, disagreements were resolved by consulting an additional member of the research team (RH). Levels of evidence for each study were rated according to the evidence categorization of the Centre for Evidence Based Medicine, as well as the Grading of Recommendations Assessment, Development and Evaluation (GRADE) Quality of Evidence Rating Scheme.[33,34] Studies using single-subject research designs were evaluated using the AACPDM Single Subject Design Levels of Evidence and Conduct Quality Ratings scales.[35]

The types of specific outcome addressed by the studies were not limited to specific movement outcomes a priori, because we hoped to discover the range of movement-related outcomes being addressed by AVG in the literature. However, studies excluded from this review included those that focused on weight control or fitness/obesity; used robotics, virtual reality, or non-commercially available systems; involved progressive disorders; did not address movement needs of the target population or include a motor outcome; did not include the use of AVG; were case studies or narrative reviews; were not available in English; were published before the year 2005 or after 2015; or planned projects that were incomplete or constituted gray literature.[29]

Once the studies were identified, the following data were extracted and analyzed: AVG use in specific neuromotor conditions; strength of the evidence; delivery methods or systems for AVG; capacity for adjusting exercise dosing to fit individual needs and skill levels; effectiveness for achieving outcomes; and the challenges and limitations described in each study.

RESULTS

The initial 2602 articles found were filtered to the final 20 using the described systematic review methodology. Data extracted from the 18 group design studies are reported in Table 4. Data extracted from the two single-subject research design studies are reported in Table 5. The findings on the chosen parameters are described below.

Sample populations by health condition

Included studies focused on children with a variety of health conditions involving the nervous system including CP (*n*=9), DCD (*n*=6), Down syndrome (*n*=2), developmental delay (*n*=1), progressive spinocerebellar ataxia (*n*=1), and acquired brain injury (*n*=1). Hereafter, diagnostic categories with only one paper are grouped together and categorized as 'other' for the results and discussion. Across health conditions, most authors defined their sample within a specific age range, severity limits, or status related to safety factors such as postoperative activity restrictions. Combining samples of all included studies created a collective population of 606 children with ages from 3 to 20 years (mean 9.0).[*] Additional characteristics of participants are detailed in Table 6.

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[*] Samples reported in the two systematic reviews were excluded from this count, either because the review did not include summarized demographic data, or because the review's data included articles that did not meet the criteria for this systematic review. The results of these two previously existing systematic reviews are summarized in the "Effectiveness for achieving outcomes" section.

Strength of evidence

All included studies using group research designs were ranked using the levels of the Centre for Evidence Based Medicine.[33] These articles included 14 level 1, three level 2, and one level 3 group design studies, as well as two level 1 single-subject research design studies. As per the AACPDM methodology, group design studies in levels 1 to 3 (*n*=18) were also rated using the GRADE[34] system. Six studies were rated as high quality, four as moderate, and eight low. The two single-subject research design studies were rated as high quality. Details of ratings and methodologies of the studies are found in Table 2. Although GRADE[26] rankings are provided, study parameters were neither homogenous nor extensive enough to allow rated recommendations.

Delivery methods or systems for AVG

The purpose, manner, and setting of delivering AVG experiences to participants also varied across included studies. Most studies (*n*=15) used AVG as an intervention tool only, while others also used it to collect performance data (*n*=3). All of the original research studies used one of three existing commercial gaming systems as their foundation. The Nintendo Wii or Wii Fit was used in 14 studies, PlayStation 2 Eye Toy was used in three studies, and the Microsoft Xbox 360 Kinect system was used in two studies (one study used both the Kinect and the Eye Toy). The details about how often each gaming system was used for the different health conditions are summarized in Figure 4.

Gaming experiences were delivered under the supervision of a therapist in a clinic (*n*=10), in a school setting (*n*=4), or unsupervised at home (*n*=5) (one study delivered AVG in a clinic initially, and then switched to home). The remaining two studies were systematic reviews, and as such did not directly administer gaming strategies themselves under any particular condition.

When AVG was used as the primary intervention approach, it seemed to be most beneficial when the children were directly supervised during play.[25,36-44] Details about how often each delivery type was used across the different health conditions are summarized in Figure 5.

Frequency and duration of AVG play varied across studies. Of the 18 studies that were not systematic reviews, there were 16 different AVG dosages, ranging from 10 minutes to 1 hour; less than once per week to 5 days per week; and for durations of 3 weeks to 24 weeks. The only dosing strategy repeated across studies delivered AVG for 30 minutes, three times per week, for 6 weeks.

Capacity for adjusting to individual needs and skill levels

There were no articles in the final extraction that studied commercially available, customizable games that could be adjusted by the therapist or the client. Any articles that involved customizable gaming software described the development and the usability of new technology that was not yet commercially available. Therefore, in the accepted articles, the 'control' options available to the therapist involved choosing specific games for the children to play (*n*=3), or setting specific, pre-programmed difficulty levels (*n*=3). In the remaining studies (*n*=12), the children were allowed to choose any game to play from a pre-set list of games available and to choose their own difficulty level. Figure 3 summarizes the control choices made by the researchers studying the different populations of children.

Effectiveness for achieving outcomes

Across the 18 original studies included in this systematic review, there were 49 different outcome measures used, which evaluated upper extremity function, lower extremity function, balance, or additional related factors (such as motivation). Results for each of these functional variables were not consistent. Some outcome measures showed significant improvement with AVG training, while others demonstrated no effect. Most (*n*=36) of these outcome measures assessed the children's abilities at the activity level of the ICF. Six outcome measures assessed impairments, and two evaluated participation.

CP

Across the nine studies evaluating children with CP, there were 20 outcome measures used. There was no repetition of outcome measures across studies: that is, no single outcome measure was used in more than one study. Nine outcome measures assessed upper extremity function, including hand function, grip strength, coordination, manual dexterity, ball skills, and general function. Most of these studies exhibited significant improvement after AVG training. However, AVG did not prove to be significantly more effective than standard care. Studies using six balance outcomes demonstrated mixed results. Three outcome measures evaluated lower extremity function, including stair climbing, walking, and running/agility. Walking improved after AVG training, but there were no improvements in stair climbing ability or running/agility performance. Researchers reported on four additional outcome measures of caregivers' perceptions, motivation, participation, and child satisfaction. All were tested in the same study and showed more improvement than the control condition of standard care. Most of these outcome measures assessed children at the ICF activity level, with one outcome measure assessing participation and one assessing impairments.

There were also two systematic reviews that studied this population. Both agreed that there was not enough high-quality evidence to fully support AVG use, and that the studies they found did not share similar study designs to compare results. Bonnechère et al. stated that the reviewed studies had mostly positive results, indicating improvements in muscle strength, balance, motivation and participation, performance, and bone density.[45] However, they also emphasized that none of these results was backed by strong evidence. Fehlings et al. reported mixed results for upper limb function and for increases in cardiovascular fitness, but found strongly supported positive results for lower-limb gross motor function.[46] This review also reported that AVG was able to provide moderate levels of activity for children.

DCD

Across the six articles that studied children with DCD, there were 16 different outcome measures used. Only the Movement Assessment Battery for Children, Second Edition and the Bruininks-Oseretsky Test of Motor Proficiency, Second Edition were used more than once. The Movement Assessment Battery for Children tests manual dexterity, ball skills, and balance. Half of the studies using this test showed improvement after AVG training, and half showed no effect. The Bruininks-Oseretsky Test evaluates fine motor precision and integration, manual dexterity, bilateral coordination, balance, running speed and agility, upper limb coordination, and strength. Children's scores on all subtests except running speed and agility increased after AVG training. Of the remaining tests, three evaluated upper extremity function (specifically coordination and strength), two tested balance skills, and six tested lower-extremity function (including walking, running, coordination, and strength). Overall, there was not a significant difference in strength before and after AVG training, and the test results for balance and the upper extremities were mixed. However, there was significant improvement on most of the tests for the lower extremities. Once again, these tests were all mostly focused on the activity level of the ICF, with three tests for impairments and one for participation.

Down syndrome

Three outcome measures were used across the two studies for this population. The children's scores for the Bruininks-Oseretsky Test, described above, improved after AVG training. The remaining two outcome measures evaluated visual perception, motor coordination, postural movement control, and various sensory and behavioral abilities. There was improvement in the scores of these two tests as well. When compared with standard care, AVG training demonstrated better results in a few test subsections and worse results in others.

Other

Across the three articles in this population group, there were 16 outcome measures used. Three of these evaluated the upper extremity function (strength, coordination, gross motor); three tested balance; nine tested the lower extremity function (walking, strength, stairs, gross motor, coordination); and three looked at children's and parents' perceptions of skills. Results for balance and perception outcomes were mixed. However, all other outcome measures showed improvement after AVG training. Only three outcome measures tested impairments, and all others evaluated the children at the activity level of the ICF.

Level 4 studies

In the article extraction, an additional eight articles were case series studies with no comparison groups, which constituted level 4 evidence and could not be included in the main evidence table as per AACPDM methodology.[36,47–53] Of these, seven studied children with CP, and one evaluated children with DCD. Results of these studies strongly reflected those reported above: outcome measures were varied, and results for AVG training generally showed improvement, with the exception of a few specific measures that showed no effect.

Challenges/limitations

Authors of the included articles identified similar limitations or threats to their studies across the different sample/diagnostic populations. The primary limitation was low statistical power due to small sample sizes.[25,37-39,54-57] Heterogeneity of subjects was listed as a limitation in four studies.[26,38,55,57]

Researchers also listed challenges related to dosing of AVG as an intervention. They cited difficulty challenging the children enough for the treatment to have made a statistically significant difference in outcomes.[54,56] The researchers also reported difficulty customizing the AVG enough to address children's individual limitations and to provide them with truly task-specific training.[37,54,56] Two studies remarked that the children may not have practiced for the required amount of time, either because of the motivation required to practice alone at home,[55] or because of false inflation of the actual amount of self-reported time playing.[56]

Another limitation described was the lack of a true comparison group, which was reported in two studies.[39,40] In the experimental design, another challenge cited was the inability to control for the daily life activity of these children.[38,40,58] These studies reported that if the children tended to play more with friends during the study time period, it may have altered their results. Three studies also listed a lack of blinding of assessors as a limitation.[25,56,58]

DISCUSSION

The purpose of this systematic review was to gather evidence about the use of AVG as a therapeutic intervention for improving motor outcomes in children with neurodevelopmental conditions. The feasibility of AVG use in all populations examined was affirmed by this review. In the body of literature searched, there was clear support for use of AVG to improve general motor function in children with neuromotor conditions. This suggests that AVG is a viable avenue to provide the practice levels required for motor improvement. However, the literature did not support use of AVG as a stand-alone intervention capable of creating permanent neuromotor improvements.

Additionally, AVG use in each population (CP, DCD, Down syndrome, or other) was generally supported by the research findings, but the overall strength of this body of literature was low. Of the articles that were included in this review, 14 were randomized control trials, of which 10 received moderate- or low-quality ratings. However, this body of literature also included two high-level systematic reviews that investigated use of AVG children with CP.[45,46] Our finding that evidence was neither strong enough nor plentiful enough to form definitive recommendations was consistent with conclusions made in those previous reviews. However, the body of literature of our systematic review included a greater number of high-quality studies than previous reviews, indicating that the available evidence on AVG use is improving.

The four high-quality randomized control trials showed promising results for AVG training.[36,40,41,58] Positive results were found for outcome measures evaluating balance, gross motor function, and upper- and lower-limb function. Although there were numerous tests and outcome measures used, most of these tools measured change at the level of impairment or capacity with regard to discrete skills. The only outcome suggesting that practice obtained through use of AVG might transfer to real-world function was the improvement in the Movement Assessment Battery for Children, Second Edition, the only outcome measure used in these four studies purporting to assess children at the ICF level of participation. None of the studies specifically tested whether AVG provided task-specific practice that carried over into real-world function. There was little or no overlap of outcome measures used among the four strong clinical trials, so results could not be combined for meta-analysis. Overall, the 49 outcome measures used across the 20 reviewed studies were generally heterogeneous, so it was not possible to make a definitive statement on whether AVG benefited these children in specific measures of upper extremity function, lower extremity function, or balance. In the combined body of literature, more outcome measures showed improvement than not, particularly those assessing lower extremity function. AVG does appear to be a promising treatment strategy to generally improve motor function in children with a variety of neuromotor conditions; however, more specific results cannot be derived. These findings reinforce the need for a standard set of outcome measures that can be used widely across research studies as well as in clinical practice touted in rehabilitation literature.

Standard physical therapy care served as the control condition for all experimental studies in which AVG was compared with other intervention strategies. Several studies showed that AVG and conventional therapy can be comparable in their results (some parameters improved more, others less), so it would be reasonable to include AVG in a training program for these children. The only repeated dosing protocol encountered in this body of literature was the delivery of AVG for 30 minutes, three times per week, for 6 weeks.[26] Our findings demonstrate that AVG holds promise as an intervention strategy for children with neurological conditions, but it was not significantly more effective than traditional pediatric rehabilitation strategies in any of the studies reviewed.

We had hypothesized that AVG would largely be touted and examined as an adjunct to traditional therapies as part of a comprehensive plan of care, especially as a home program strategy used to increase the volume of practice of functional tasks. However, researchers in only four of the studies combined AVG training with standard care, all of which occurred in a clinical context. It would be helpful to examine the effects of AVG training as a home exercise program and adjunct to traditional physical therapy. This may give children the best of both worlds: skilled treatment from a trained therapist, and the volume of task-specific practice provided with a home exercise program.

Owing to the heterogeneous nature of the populations, outcome measures, and protocols for AVG use, it is not possible to make formal recommendations about its use at this time. However, some trends do emerge as we consider the group of 20 studies as a whole. Direct supervision during AVG participation was associated with greater improvements in AVG-dependent motor outcomes. This may be true because the child's effort and volume of practice can be more effectively determined by their therapist. A second condition in which AVG seems to work well is when the games' level of difficulty can be adjusted to provide a personalized 'just right' challenge for each child.[36,37] A third is outcome specificity, in which therapists choose specific games that target the individual child's desired outcomes.[37,40,44] On their own, the children tended to choose games that were easier for them to play, which did not challenge them to develop more skilled movement.

There was little variation in the type of AVG technology used across studies, with nearly all the 20 studies using the Nintendo Wii as it was commercially designed. This may change with the development of new games using the Microsoft Xbox 360 Kinect or other gaming platforms that potentially offer more control to therapists, but these are not yet commercially available.[59]

Like the 20 studies reviewed, this review has its own limitations. We did not consider non-English articles. We also did not include gray literature in the group of articles reviewed. These criteria may have limited our findings. Further, the largest quantities of evidence in this body of literature studied children with CP and (slightly less so) DCD. There were no studies at level 3 or higher evaluating the use of AVG for children with autism or epilepsy.

CONCLUSION

Clinical Bottom Line: This review has shown that AVG is a feasible treatment strategy for several populations of children, and it is most likely a beneficial addition to traditional physical therapy. These findings suggest that AVG is most effective when used under the direct supervision of therapists who select the specific games to match each child's specific impairments and set the degree of difficulty for the children. However, specific recommendations on its use and effectiveness cannot be made, owing to the heterogeneous nature of the data.

Future Research: Further research is warranted to explore the use of AVG, including larger sample sizes of children and the use of more homogenous outcome measures. Important questions to be asked in future studies include inquiries that illuminate optimal dosing of AVG, whether AVG actually provides the type of task-specific practice necessary to achieve transfer of skills to real-life function, and identification of the mechanisms by which AVG contributes to improved function. In addition, as AVG was shown to be potentially beneficial to samples of children with neurological motor dysfunction, its use in other subgroups of this population such as those with autism or epilepsy should be studied. Finally, the development of commercially available games with more control options available to the therapist is also justified by our findings.

APPENDIX A: TABLES

Table 1. Evidence Quality Categorization

CEBM Level[33]	Study Design	Definition[60]	GRADE Evidence Rating[34]
1a	Systematic Review of Randomized Control Trials (RCTs)	Article composed by systematic search, appraisal, and summary of all RCTs in the medical literature for a specific topic.	NA
1b	Randomized Control Trial	Randomized group of patients in an experimental and control groups to assess a specific outcome.	High or Moderate
2a	Systematic Review of Cohort Studies	See "1a – Systematic Review…", but with respect to cohort study literature.	High or Moderate
2b	Cohort Study	Two groups (cohorts) of patients, receiving and not receiving the exposure of interest, and observing for the outcome of interest.	Low or Very Low
3a	Systematic Review of Case-Control Studies	See "1a – Systematic Review…", but with respect to case-control study literature.	NA
3b	Case-Control Study	Examines intervention exposure in patients who have the outcome of interest (cases) and controls who don't.	Low or Very low
4	Case-Series (and poor quality cohort and case-control studies)	Case-Series: A series of case reports involving patients who were given similar treatment. Poor quality refers to inconsistent treatment/ assessment of the participants.	Low or Very low
5	Background Information/Expert Opinion	Handbooks, encyclopedias, and textbooks often provide a good foundation or introduction.	NA

Table 2. GRADE Quality of Evidence Rating Scheme[34]

GRADE Criteria	Quality Adjustment Factor	Criteria for Adjustment
Large Effect	1+ Large 2+ Very Large	• Presence of a large magnitude of effect representing a two-fold to five-fold increase/reduction in risk • Specific for Observational Studies
Dose Response	1+ Large 2+ Very Large	• Presence, or likelihood, of a dose-response gradient • Specific for Observational Studies
All Plausible Confounding	1+ Large 2+ Very Large	• All plausible confounders/other biases increase confidence in estimated effect • Specific for Observational Studies
Study Limitations (Risk of Bias)	1- Serious 2- Very Serious	• Insufficient participant allocation concealment • Insufficient research blinding • Insufficient accounting of patients/outcome events • Selective outcome reporting bias • Stopping early for benefit • Use of non-validated outcome measures
Publication Bias	1- Serious 2- Very Serious	• Evidence for outcomes comes from small studies • Available studies are mostly industry sponsored • Study authors reveal conflicts of interest • Presence of an asymmetrical funnel plot: compares magnitude of the effect size against the precision of the estimate of the effect
Imprecision	1- Serious 2- Very Serious	• Calculated boundaries of the confidence interval would alter clinical action • Large effect, with robust confidence intervals, with a small total sample size and number of interaction events

Inconsistency	1- Serious
	2- Very Serious
		• Large heterogeneity in study results based on:
		  • Similarity of point estimates
		  • Extent of overlap of confidence intervals
		  • Statistical criteria including tests of heterogeneity and I^2

Indirectness	1- Serious
	2- Very Serious
		• Presence of application indirectness:
		  • Patients differ from those of interest
		  • Intervention differs from intervention of interest
		  • Surrogate outcomes reported, investigator choice of previously non-compared interventions without analysis of patient populations, co-interventions, measurements of the outcomes, etc.

Tier 1= total number of articles
Tier 2=number after deletion by title
Tier 3=number after deletion by abstract

Table 3. Results of Article Search

Key Terms	**Databases**				
	Scopus	MEDLINE	Cochrane	EMBASE	CINAHL
Active video games AND physical therapy	38 4 3	2 0 0	20 3 2	4 1 1	2 1 1
Active video games AND rehabilitation	54 5 3	7 2 2	13 2 2	9 1 1	2 1 1
Active video games AND cerebral palsy	15 9 4	3 3 2	1 0 0	5 1 1	2 1 1
Active video games AND autism	5 3 0	0 0 0	0 0 0	0 0 0	0 0 0
Active video games AND brain injury	3 2 1	0 0 0	3 1 1	1 0 0	0 0 0
Active video games AND developmental coordination disorder	3 3 3	2 0 0	2 2 2	1 1 1	0 0 0
Active video games AND down syndrome	0 0 0	0 0 0	1 1 1	0 0 0	0 0 0
Active video games AND epilepsy	2 0 0	0 0 0	1 1 1	0 0 0	0 0 0
Active video games AND fetal alcohol syndrome	0 0 0	0 0 0	1 1 1	0 0 0	0 0 0
Active video games AND neuromuscular disease	1 0 0	0 0 0	1 1 1	0 0 0	0 0 0
Active video games AND neurodevelopmental disorder	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0
Active video games AND movement disorder	8 6 3	0 0 0	1 1 1	0 0 0	0 0 0

Key Terms	**Databases**				
	Scopus	MEDLINE	Cochrane	EMBASE	CINAHL
Interactive video games AND physical therapy	73 21 4	2 1 1	14 2 2	2 2 0	0 0 0
Interactive video games AND rehabilitation	137 16 5	6 2 2	22 3 3	8 3 2	2 0 0
Interactive video games AND cerebral palsy	28 16 10	3 2 2	2 2 2	3 3 3	0 0 0
Interactive video games AND autism	22 2 0	1 0 0	1 0 0	1 1 0	1 0 0
Interactive video games AND brain injury	4 2 1	0 0 0	2 1 1	0 0 0	0 0 0
Interactive video games AND developmental coordination disorder	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0
Interactive video games AND down syndrome	2 0 0	0 0 0	1 1 1	0 0 0	0 0 0
Interactive video games AND epilepsy	2 1 1	0 0 0	1 1 1	0 0 0	0 0 0
Interactive video games AND fetal alcohol syndrome	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0
Interactive video games AND neuromuscular disease	0 0 0	0 0 0	1 1 1	0 0 0	0 0 0
Interactive video games AND neurodevelopmental disorder	2 0 0	0 0 0	1 0 0	0 0 0	0 0 0
Interactive video games AND movement disorder	19 9 3	0 0 0	2 1 1	0 0 0	0 0 0

Key Terms	**Databases**				
	Scopus	MEDLINE	Cochrane	EMBASE	CINAHL
Exergames AND physical therapy	45 6 0	1 0 0	15 3 0	1 1 1	2 2 2
Exergames AND rehabilitation	79 17 3	2 0 0	8 0 0	5 3 3	8 5 4
Exergames AND cerebral palsy	5 5 2	0 0 0	0 0 0	2 2 2	3 2 2
Exergames AND autism	10 6 2	1 1 1	0 0 0	0 0 0	1 1 1
Exergames AND brain injury	1 0 0	0 0 0	0 0 0	0 0 0	0 0 0
Exergames AND developmental coordination disorder	1 0 0	0 0 0	0 0 0	0 0 0	1 1 1
Exergames AND down syndrome	2 1 1	0 0 0	0 0 0	0 0 0	0 0 0
Exergames AND epilepsy	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0
Exergames AND fetal alcohol syndrome	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0
Exergames AND neuromuscular disease	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0
Exergames AND neurodevelopmental disorder	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0
Exergames AND movement disorder	6 3 2	0 0 0	1 0 0	0 0 0	0 0 0

Key Terms	Databases				
	Scopus	MEDLINE	Cochrane	EMBASE	CINAHL
Video games AND physical therapy	268 47 17	26 16 14	71 5 5	16 7 6	8 6 6
Video games AND rehabilitation	498 127 34	94 32 29	103 11 7	48 17 14	29 12 9
Video games AND cerebral palsy	81 46 26	34 31 8	13 8 5	22 12 11	12 9 8
Video games AND autism	91 2 0	19 1 0	4 0 0	21 1 0	15 1 0
Video games AND brain injury	64 14 2	11 5 4	11 1 1	9 2 2	6 3 1
Video games AND developmental coordination disorder	12 7 5	4 3 2	2 2 2	1 1 1	2 1 1
Video games AND down syndrome	10 1 1	1 1 1	2 1 1	0 0 0	0 0 0
Video games AND epilepsy	79 0 0	9 0 0	4 1 1	11 0 0	0 0 0
Video games AND fetal alcohol syndrome	2 0 0	0 0 0	1 0 0	2 0 0	1 0 0
Video games AND neuromuscular disease	9 0 0	0 0 0	1 1 1	1 0 0	0 0 0
Video games AND neurodevelopmental disorder	9 0 0	0 0 0	1 0 0	0 0 0	1 0 0
Video games AND movement disorder	79 13 9	0 0 0	7 3 3	0 0 0	0 0 0

Table 4: Details of Extracted Articles: Study Design, Samples and Results

	STUDY DESIGN					SAMPLE AND RESULTS			
STUDY	CEBM Level/ Quality of Evidence	AVG Exposure	Manipulation	Dependent Variable	Limitations	Size (N)	Health Condition	Platform/ game	Key Findings
ABDEL RAHMAN ET AL.[42] (2010)	1b, Moderate	Clinic, supervised	Control: one hour sessions (approximation and strengthening for 20-min, walking and climbing stairs for 35 min, rests); Experimental: approximation and strengthening for 15min, walking and climbing for 15-min, Wii games for 15 min, rests); 2x/wk for 6 weeks	BOTMP	N/A	30	Children with Down Syndrome, 10-13 y.o., mild-moderate mental retardation; IQ from 36-67	Wii Fit with Wii Balance Board; Games: foot ball heading, tight rope walk, Penguin slide game	Experimental: significant improvement compared to control (postural stability)
ALSAIF ET AL.[61] (2015)	1b, Moderate	Home, unsupervised	Experimental: AVG 20-min/day for 12 weeks; Control: no treatment	mABC-2; BOTMP subsets 5:6 (touching a swinging ball, upper limb coordination); one-minute walk test	N/A	40	Children with CP, 6-10 y.o., GMFCS level III	Nintendo Wii Fit (20 included games)	Experimental: significant improvement in all parameters; control: no improvement
ASHKENAZI ET AL.[36] (2013)	1b, High	Clinic, supervised	Experimental: 10, 60-min sessions over 12 weeks, AVG: increasing levels of difficulty of games; Control: Conventional treatment using equipment in typical PT clinic, played games with PT or parent (bowling, etc.); last 10-min of treatment of both groups was a task/goal-specific exercise	mABC-2; DCDQ-07; Parent's subjective report; Walking and Talking Test; Short Feedback Questionnaire for Children	N/A	30	Children with DCD, 4-6 y.o., mABC-2 <15th%	PlayStation 2 EyeToy	Significant improvement in mABC-2 (both groups), Significant pre-post improvements for both groups in the "walk with tray" condition. Both groups demonstrated significant pre-

									post improvement for overall score in the DCDQ.
CHIU ET AL.[58] (2014)	1b, High	Home, supervised (by therapist 1x/wk, parent 2x/wk)	Control: usual therapy; Experimental: 40-min/day, 3x/wk for six weeks	Coordination (tracking task), grip strength, hand function (Nine-hole Peg Test and the Jebsen-Taylor Test of Hand Function), carers' perception of hand function questionnaire	Randomization not fully concealed; Allocation sequence not hidden during recruitment	62	Children with CP, 6-13 y.o.	Wii Sports Resort: Bowling, Air Sports, Frisbee, and Basketball	No difference in coordination or hand function; trend for AVG group to have improved grip strength and carers' perception of quantity of hand function, maintained for weeks 6-12; Improved Wii scores
HAMMOND ET AL.[25] (2014)	1b, Low	School, supervised (Teachers Assistant); children chose from 9 games	Crossover: Four weeks of 10-min supervised play 3x/wk; four weeks of normal school "jump ahead" program (motor skill practice), 1hr/wk	BOT-2; self-perceived ability-CSQ; Strength and Difficulties questionnaire by parent	One child withdrew due to concerns of potential stigmatization; small sample size; lack of blinding	18	School children 7-10 y.o. with DCD: bottom quintile DCDQ	Wii Fit and 9 associated games focusing on balance and coordination	Significant BOT-2 improvement in experimental group from baseline to end of phase 1; CSQ of groups together improved over time; improvement reported in individual children and subscores
JANNICK ET AL.[54] (2008)	1b, Low	Supervised; PT chose which games played and in what order	Experimental: AVG+regular PT; Control: regular PT only; both: 30-min 2x/wk for six weeks	The Melbourne Assessment of Unilateral Upper Limb Function	Sample size 10; difficult to fully challenge children, could not match difficulty of games to child's ability	10	Children with CP; 5-15 y.o.	PlayStation 2 EyeToy Play; Games: Kung Fu, Wishi Washi, Keep Ups	Maximum Melbourne Assessment improvement of control was 5%; max of intervention (AVG) was 13%

JELSMA ET AL.[43] (2014)	1b, Moderate	School, supervised	Two groups of children with BP: One had AVG intervention for 30-min, 3x/wk for six weeks, other had no intervention for six weeks, then AVG for six weeks; TD: no intervention, tested before and after six weeks	mABC-2; 3 subsets of BOT-2 (bilateral coordination, balance and running speed and agility); Wii Fit ski slalom test	N/A	28 with BP, 22 TD	Children with DCD age 6-12 y.o. and BP, <16th% on mABC-2 and component score for balance; TD children, >16th% of mABC-2	Nintendo Wii Fit Plus; Games (18 different titles)	Significantly improved on all variables except mABC-2 aiming and catching and manual dexterity subsets, and the time needed to complete the Wii ski slalom test; dynamic control and balance improved per the BOT-2 in 18 children
MOMBARG ET AL.[37] (2013)	1b, Moderate	School, supervised trained physical education students/PT	Control: no intervention; Experimental*:* initial balance-test on Wii-balance board to determine appropriate difficulty level; difficulty automatically adjusted as needed*;* three sessions of 30-min/wk for six weeks	mABC-2; BOT-2	Type of assessment (not task specific in real life situation, does not reveal balance strategy); only 6 female participants; effect could be due to attention of trainer (Hawthorne Effect)	29	Children with DCD, age 7-12 y.o., mABC-2 <16th%	Wii Fit Plus with Wii Balance Board; each session children chose 3-5/18 balance games (ski-jump, segway circuit, obstacle course, skate boarding, ski-slalom, table tilt, snowboard slalom, tilt city, rhythm)	mABC-2 and BOT-2 increased significantly in experimental group only; "small to medium intervention effect on balance in general"; no change on BOT-2 running speed and agility
RAMSTRAND ET AL.[55] (2012)	1b, Low	Home, unsupervised, choice of any game out of the options	Crossover: AVG 30-min, 5x/wk for five weeks; five weeks of no intervention	Rhythmic weight shift balance testing using PRO Balance Master (neuroCom); standing balance via mSOT; reactive balance test via EMG;	Six subjects did not complete study: difficulty practicing for the required amount of time, *one subject* did not want to complete all testing; small	18	Children with CP, 8-17 y.o., GMFCS of I-II	Nintendo Wii Fit and Wii Balance Board; Games: Soccer Heading, Ski Slalom, Ski Jump, Table Tilt, Tightrope Walk,	No significant effects for mSOT, rhythmic weight shift, or reactive balance test

					heterogeneous sample size; children chose games, may not have chosen challenging ones			Balance Bubble	
SALEM ET AL.[14] (2012)	1b, High	Clinic, supervised (PT/OT)	Experimental: individualized Wii training; Control: individualized traditional PT treatment; 30-min 2x/wk for 10 weeks	Gait speed (10m walking test), TUG Test, the single leg stance test, the five times sit to stand test, the timed up and down stairs test, the 2-minute walk test and grip strength, GMFM-88	No control for physical activity of children outside clinical site; no true control group; focused only on children with mild impairment; not supervised in the home;	40	Children with development al delay, 3-5 y.o., no previous experience with the Nintendo Wii	Nintendo Wii Sports and Wii Fit; Games: Lunges and Single Leg Stance, Soccer Heading, Penguin Slide, Tightrope, Basic Run, Hula Hoop, Basic Step, Baseball, Boxing, Bowling	All variables were significantly improved in both groups from baseline to post-intervention; experimental group had greater single leg stance and grip strength improvement
SHARAN ET AL.[44] (2012)	1b, Low	Clinic, supervised	Experimental: AVG+conventional rehabilitation played every three alternate days in a week for three weeks, games chosen for each participant; Control: conventional rehabilitation	MACS, PBS, level of participation, motivation, cooperation and satisfaction of child	N/A	16	Children with CP, postoperative	Nintendo Wii Sports and Wii Fit; *Games:* Play Tennis, Baseball, Golf, Bowling, and Boxing	Significant improvement in MACS and PBS for both groups; Experimental: Significant improvement more on balance score, not manual ability score; participation, satisfaction, cooperation, and motivation were higher for experimental group
SHIN ET AL.[38] (2015)	1b, Low	Clinic, supervised (PT)	Experimental: 30-min of therapeutic exercise, 15-min of AVG training 2x/wk for eight weeks	K-DTVP-2 eye-hand coordination and visual-	Small sample size; could not control for daily life	16	Children with CP, GMFCS	Nintendo Wii	Both groups improved significantly; no difference

			Control: conventional neurological PT, 45-min 2x/wk for eight weeks;	motor speed subsets	activity; only tested children with spastic palsy of both lower limbs		*stage* I-III, 4-8 y.o.		between the groups
STRAKER ET AL.[22] (2015)	1b, Moderate	Home, unsupervised	Crossover: Normal activity for 16 weeks, AVG for 16 weeks, children chose games; played ≥ 20-min most days, min of 4-5x/wk	mABC-2; 3D analysis of finger to nose and SLB task; DCDQ; child rating of motor coordination; performance on 4 different AVG titles (move table tennis, move archery, Kinect table tennis, Kinect soccer) new sport participation	Small sample size; assessment by non-blinded physical education teacher; no parent/therapist supervision, child reported compliance; did not target specific areas of coordination	21	Children with DCD, 10-12 y.o., ≤16th% mABC-2, ≤15th% DCDQ;	Sony PlayStation 3 with Move and Eye, Xbox 360 with Kinect; Games: Sports Champions, Start the Party, TV Superstars, EyePet, Your-shape Fitness Evolved, Motion Sports, Kinect Adventures, Free Riders, Dance Central, Dr. Kawashima's Body and Brain Exercises; Racket Sports, Cross Board 7	No significant effects other than child's perception of increase in physical skills
WUANG ET AL.[41] (2011)	1b, High	Clinic, supervised	Treatment: one hour session 2x/wk for 24 weeks	BOT-2; VMI; TSIF	Could not control for practice/ physical activity amount at home; no long-term follow up	155: 50 controls (no treatment), 105 randomly assigned to either standard OT or AVG	Children with down syndrome, 7-12 y.o.	Nintendo Wii Sports	Both treatment groups significantly improved compared to control in all measures; AVG group outperformed standard OT in TSIF (except sensory discrimination)

									and BOT-2 fine motor integration, upper-limb coordination, and running speed and agility subsets; standard OT better in BOT-2 subtest manual dexterity and TSIF subtests sensory discrimination and sensory modulation
BONNECHÈRE ET AL.[45] (2014)	2a (Systematic Review of Cohort Studies), High	All AVG	Databases: Academic OneFile, ERIC, PubMed, ScienceDirect, Scopus; search terms: serious gaming, serious games, virtual reality, tele-rehabilitation, virtual environment, computer game, exergaming	N/A	N/A	31 papers, 352 patients	Children with CP	18 studies used specially developed games, 13 studies explored commerciall y available AVG	Little evidence to support the non-AVG treatments in use; AVG: studies did not have similar approaches, not enough high quality studies to support anything, even though the studies mostly had positive results: improved muscle strength, balance, motivation/partic ipation, performance, bone density
FEHLING ET AL.[46] (2013)	2a (Systematic Review of Cohort Studies), High	All AVG	Databases: MedLine, Cochrane, PsycINFO, CINAHL; search terms: computer play, VR, exergames, gross motor, muscle strength, manual ability, and commercially available games	N/A	N/A	17 articles	Children with CP	Any AVG	Upper limb: results mixed, some studies showed improved function (unproven level), some did not, improved quality of movement; lower limb: gross motor

									improvements, probably effective level; CVS fitness: moderate levels of activity, but conflicting evidence on CVS fitness
FERGUSON ET AL.[26] (2013)	2b (Individual Cohort Study – Single Blinded, Quazi-Experimental Design), Low	School, supervised	Control: NTT, 45-60-min 2x/wk for nine weeks; experimental: AVG 30-min, 3x/wk for six weeks	mABC-2; handheld dynamometer; FSM; Muscle Power Sprint Test; 20m Shuttle Run Test	Frequency and duration of two treatments was different; co-morbidities not accounted for	56	Children with DCD, 6-10 y.o., <16th% on mABC-2	Nintendo Wii Fit and Wii Balance Board; 13 games that mimicked the act of cycling, soccer, skateboarding and skiing games	No significant mABC-2 difference between groups, but both groups improved over time; total standard mABC-2 score: NTT improved, Wii did not; FSM: both improved, NTT more; both improved in aerobic and anaerobic exercise (Wii more aerobic, NTT more anaerobic)
ILG ET AL.[62] (2012)	3b (Individual Case-Control Study – Intra-individual Control Design), Low	Laboratory/ Home, supervised: two weeks followed by home environment, six weeks	Weeks 1-2: one hour, 4x/wk; Weeks 3-8: at home, daily, parents recorded AVG exposure volume	SARA; DGI; quantitative movement analysis (2 weeks before intervention, after 1st training session, after 2 weeks, after 6 weeks); ABC, self-rated	N/A	10	Children with progressive spinocerebellar ataxia, 8-20 y.o., SARA total >3, SARA gait <4 at baseline	Microsoft Xbox Kinect; Games: Table Tennis, Light Race, 20000 Leaks	Game performance improved; improved SARA improved; DGI scores increased; ABC not significant; decrease in step variability, decrease in lateral sway: improved dynamic balance and decreased risk of falling; decrease in leg placement errors

ABC, Activity-specific Balance Confidence Scale; AVG, Active Video Gaming; BOT-2, Bruininks-Oseretsky Test – 2nd edition; BOTMP, Bruininks-Oseretsky Test of Motor Proficiency; BP, Balance Problems; CP, Cerebral Palsy; CSQ, Coordination Skills Questionnaire; DCD, Developmental Coordination Disorder; DCDQ(-07), Developmental Coordination Disorder Questionnaire 2007; DGI, Dynamic Gait Index; FSM, Functional Strength Measure; GMFM-88, Gross Motor Function Measure; K-DTVP-2, Korean-Developmental Test of Visual Perception – Second Edition; mABC-2, Movement Assessment Battery for Children – Second Edition; MACS, Manual Ability Classification System; MFRT, Modified Functional Reach Test; mSOT, Modified Sensory Organization Test; OT, Occupational Therapy; NTT, Neuromotor Task Training; PBS, Pediatric Balance Score; PEDI, Pediatric Evaluation of Disability Index; PMS, Pediatric Motivation Scale; PT, Physical Therapy; SARA, Scale for the Assessment and Rating of Ataxia; SLB, Single Leg Balance; TD, Typically Developing; TSIF, Test of Sensory Integration Function; TUG, Timed Up and Go; VMI, Developmental Test of Visual Motor Integration

Table 5: Details of Extracted Single Subject Research Design Articles: Study Design, Samples, and Results

	STUDY DESIGN					SAMPLE AND RESULTS			
STUDY	Level/ Quality of Evidence	AVG Exposure	Manipulation	Dependent Variable	Limitations	Size (N)	Health Condition	Platform/ game	Key Findings
JELSMA ET AL.[39] (2013)	I, strong	Clinic, supervised	Experimental (B Condition: AVG for 25-min, 4x/wk for three weeks Control (AB) :PT sessions for 30-min, 2x/wk)	BOT-2 balance and running and speed and agility subsets, Timed Up and Down Stairs	Small sample size, no true control group (though multiple baseline design was used); possible practice effect for tests	14	Children with CP, 7-14 y.o, GMFCS I-II	Nintendo Wii Fit and Wii Balance Board; games: snowboarding, skiing, penguin game, soccer, bubble game, hula hoop (balance and coordination)	Significant improvement in balance, but no significant improvement in running speed and agility subsets and Timed Up and Down Stairs (some children scored worse)
TATLA ET AL.[57] (2014)	I, strong	Clinic, supervised	Control: 30-min of daily balance rehab, 5x/wk; concurrent therapies (1hr speech/language therapy, 3x/wk; 1hr aquatic therapy 2x/wk); Experimental: 30-min/day; 4 weeks overall treatment; AVG introduced at different times, random	TUG test; MFRT; Wii-Fit Balance Board, PMS; PEDI	P1 displayed largest impairment and largest improvement; Wii Balance Board not sensitive enough for this population; length of baseline and intervention phases too short (data too variable); small sample size; heterogeneity of this population	3	Children with acquired brain injury, 5-18y.o.; Rancho Los Amigos level I-II (peds) or VII-VIII (adult)	Nintendo Wii Fit and Wii Balance Board; children chose games, therapists decided on difficulty level of game	TUG improved during AVG, but not more than improvement in baseline (especially in P1, longest AVG period); MFRT: improved in P1, variable in P2 and P3; static balance: inconclusive; PMS: improved with AVG in P1; P2 and P3 just verbally expressed motivation, no change on test; PEDI improved for all 3 pts, magnitude of change did not correlate with length of intervention; AVG safe and feasible for this population

ABC, Activity-specific Balance Confidence Scale; AVG, Active Video Gaming; BOT-2, Bruininks-Oseretsky Test – 2nd edition; BOTMP, Bruininks-Oseretsky Test of Motor Proficiency; BP, Balance Problems; CP, Cerebral Palsy; CSQ, Coordination Skills Questionnaire; DCD, Developmental Coordination Disorder; DCDQ(-07), Developmental Coordination Disorder Questionnaire 2007; DGI, Dynamic Gait Index; FSM, Functional Strength Measure; GMFM-88, Gross Motor Function Measure; K-DTVP-2, Korean-Developmental Test of Visual Perception – Second Edition; mABC-2, Movement Assessment Battery for Children – Second Edition; MACS, Manual Ability Classification System; MFRT, Modified Functional Reach Test; mSOT, Modified Sensory Organization Test; OT, Occupational Therapy; NTT, Neuromotor Task Training; PBS, Pediatric Balance Score; PEDI, Pediatric Evaluation of Disability Index; PMS, Pediatric Motivation Scale; PT, Physical Therapy; SARA, Scale for the Assessment and Rating of Ataxia; SLB, Single Leg Balance; TD, Typically Developing; TSIF, Test of Sensory Integration Function; TUG, Timed Up and Go; VMI, Developmental Test of Visual Motor Integration

Table 6. Demographic characteristics of sample populations by health condition

Health condition	*n* (%)	Age range (y)	Mean age	Severity tool and range
Cerebral palsy	176 (29.0)	5–17	10y 1mo	GMFCS levels I–III
DCD	192 (31.7)	4–12	8y 4mo	MABC-2 scores of either ≤15th centile or ≤16th centile, or a DCD score ≤15th centile
Down syndrome	185 (30.5)	7–13	9y 10mo	
Developmental delay	40 (6.6)	3–5	4y 0mo	
Progressive cerebellar ataxia	10 (1.7)	8–20	15y 6mo	SARA score >3 and SARA gait score <4
Acquired brain injury	3 (0.5)	5–18	13y 0mo	Rancho Los Amigos level I–II for the pediatric version or VII–VIII for the adult version
Total	606 (100)	3–20	9y 0mo	

GMFCS, Gross Motor Function Classification System; DCD, developmental coordination disorder; MABC-2, Movement Assessment Battery for Children - Second Edition; SARA, Scale for the Assessment and Rating of Ataxia.

Table 7. Details of CEBM levels and GRADE quality ratings

	CEBM levels			**GRADE quality rating**			**SSRD level**	**SSRD quality**
Health Condition	**1**	**2**	**3**	**high**	**moderate**	**low**	**1**	**high**
CP	n=6	n=2		n=3		n=5	n=1	n=1
DCD	n=5	n=1		n=1	n=3	n=2		
Down Syndrome	n=2			n=1	n=1			
Other	n=1		n=1	n=1		n=1	n=1	n=1
total	n=14	n=3	n=1	n=6	n=4	n=8	n=2	n=2

APPENDIX B: FIGURES

Figure 1: AACPDM Single Subject Design Levels of Evidence Scale[35]

Level	Evidence
I	Randomized controlled N-of-1 (RCT), alternating treatment (ATD), and concurrent or non-concurrent multiple baseline designs (MBSs) with clear-cut results; generalizability if the ATD is replicated across three or more subjects and the MBD design consists of a minimum of three subjects, behaviors or settings.
II	Non-randomized controlled, concurrent MBD with clear-cut results; generalizability if design consists of a minimum of three subjects, behaviors, or settings.
III	Non-randomized, non-concurrent, controlled MBD with clear-cut results; generalizability if design consists of a minimum of three subjects, behaviors or settings.
IV	Non-randomized, controlled SSRDs with at least three phases (ABA, ABAB, BAB, etc.) with clear-cut results; generalizability if replicated across five of more different subjects.
V	Non-randomized controlled AB single-subject research design with clear-cut results; generalizability if replicated across three or more different subjects.

Figure 2: AACPDM Single Subject Design Conduct Quality Ratings Scale[30,35]

Quality Rating Guideline

- Strong — Article meets $\geq$ 9 of the criteria listed below
- Moderate — Article meets 5-8 of the criteria listed below
- Weak — Article meets $\leq$ 4 of the criterial listed below

Quality Rating Criteria

1. Was/were the participant(s) characteristics sufficiently described to account for variables related to the research question, which could affect outcomes?
2. Were the setting and other contextual conditions operationally defined to allow replication by other researchers?
3. Were the independent variables (interventions) operationally defined to allow replication by other researchers?
4. Was the design replicated across three or more subjects?
5. Were the dependent variables operationally defined as dependent measures (target behaviors or outcomes)?
6. Was inter-rater or intra-rater reliability of the dependent measures (outcomes) assessed before and during each phase of the study?
7. Was the outcome assessor unaware of the phase of the study (intervention vs. control) in which the participant was involved?
8. Was stability of the data demonstrated in baseline, namely consistency in the target behavior over the duration of data collection
9. Were there an adequate number of data points in each phase (minimum of three) for each participant?
10. Did the graphs used for visual analysis follow standard conventions, for example x- and y- axes labeled clearly and logically, phases clearly labeled (A,B, etc.) and delineated with vertical lines, data paths separated between phases, consistency of scales?
11. Given the data available, did the authors report an appropriate approach to analysis to answer the research question?
12. In their discussion, do the authors accurately reflect the results reported?

Figure 3: Flow Diagram of Included Articles

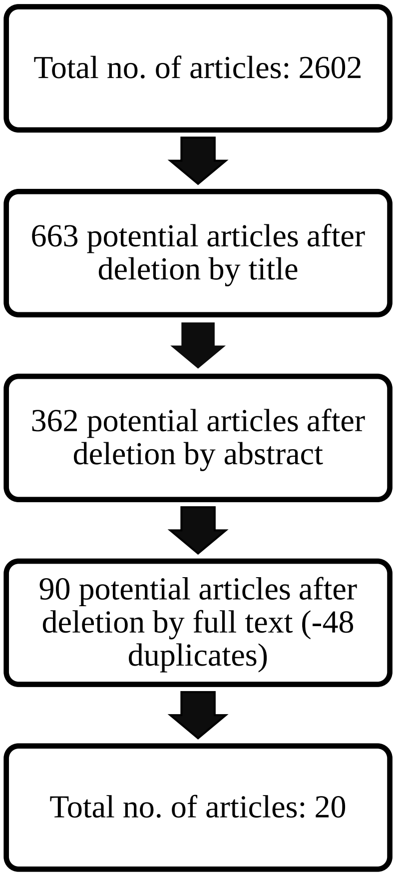


Figure 4: Gaming Systems Used Across the Health Conditions

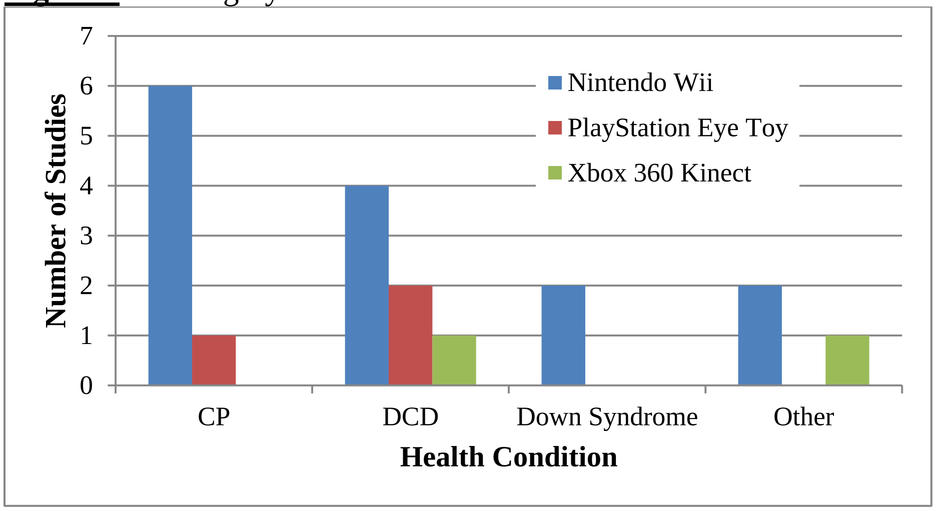


Figure 5: Delivery Types Used for Each Health Condition

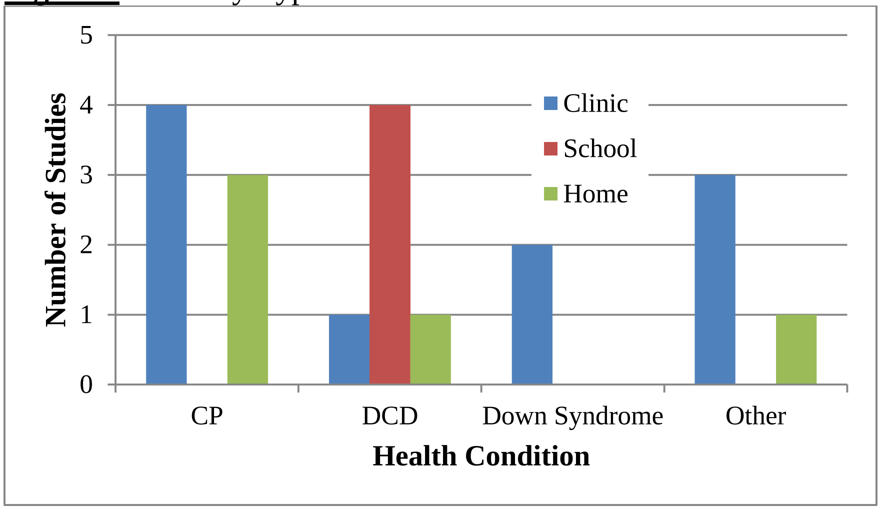
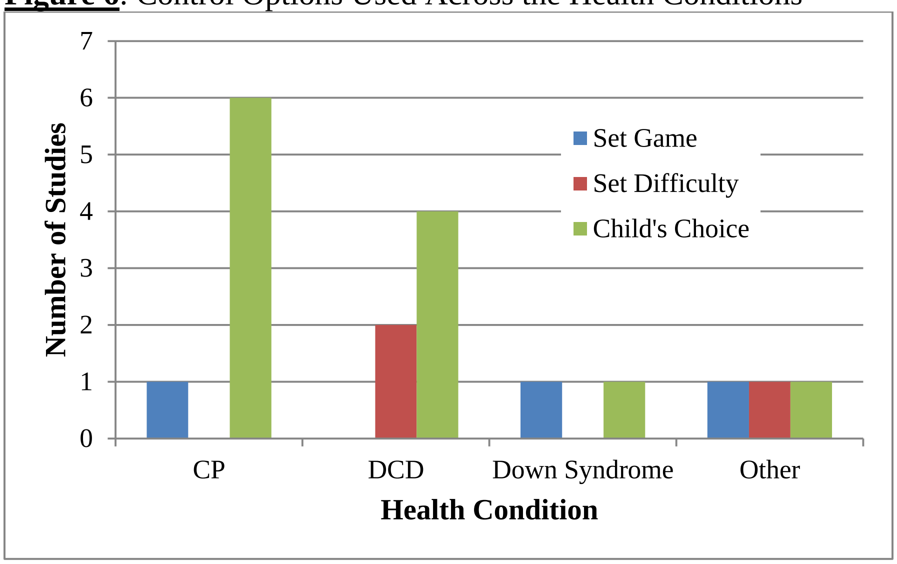


Figure 6: Control Options Used Across the Health Conditions



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CURRICULUM VITAE

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Education

- Doctorate of Physical Therapy, University of Nevada-Las Vegas (UNLV). Las Vegas, NV. Anticipated May 2017
  - Extraordinary Coursework: Biomechanics, Vestibular Rehab, Manual Therapy, Pain Science, Wound Care
- Bachelor of Science in Exercise Physiology. University of Utah. Salt Lake City, UT. June 2013.

Clinical Experience

- Sunrise Hospital and Medical Center: Las Vegas, Nevada. January-March 2017.
  - Clinical internship
  - Acute physical therapy
- HealthSouth Rehabilitation Hospital: Henderson, Nevada. October-December 2016.
  - Clinical internship
  - Inpatient rehabilitation physical therapy
- Comprehensive Therapy Centers: Henderson, Nevada. July-September 2016.
  - Clinical internship
  - Outpatient orthopedic physical therapy
- Northeastern Nevada Regional Hospital: Elko, Nevada. June-August 2015.
  - Clinical internship
  - Acute/Outpatient rehabilitation physical therapy

Continuing/Supplemental Education

- Pain Seminar: Dr. Adriaan Louw. April 2016.
- APTA Combined Sections Meeting: Anaheim, CA. February 2016.
- UNLVPT Distinguished Lecture Series: Shaw Bronner, PT, PhD, OCS--“So you want to treat dancers?” November 2015
- UNLV Physical Therapy Graduate School Class of 2015 Thesis Presentations. May 2015.
- Pain Seminar: Dr. Adriaan Louw. April 2015.
- APTA lecture: Dr. McGee—New and controversial anterolateral ligament of the knee. April 2015.
- UNLVPT Distinguished Lecture Series: Timothy Flynn, PT, PhD—“America is in Pain—Physical Therapy Solution.” November 2014.

Professional Association Membership

- American Physical Therapy Association (APTA) member since 2014.
- Nevada Physical Therapy Association (NPTA) member since 2014.
- American Heart Association Healthcare Provider CPR and AED Certification since April 2015.

- Expires in April 2017

Research Experience

- Personal Doctoral Research. Defense Date May 2017.
    - Manzanares R, Popescu L. Use of Active Video Gaming in Children with Neuromotor Dysfunction: A Systematic Review.
- Shared Authorship of Article Publication: Journal of Molecular & Cellular Cardiology (2013)
    - Insulin suppresses ischemic preconditioning-medicated cardioprotection through Akt-dependent mechanisms.

Scholarships and Awards

- UNLVPT Student Opportunity Research Grant awarded 2015.
    - Manzanares R, Popescu L. Use of Active Video Gaming in Children with Neuromotor Dysfunction: A Systematic Review.
- UNLVPT Scholars Award. February 2014.
- American Heart Association Undergraduate Student Research Program Grand 2012

CURRICULUM VITAE

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Education

- ❖ Doctorate of Physical Therapy, University of Nevada-Las Vegas (UNLV). Las Vegas, NV. Anticipated May 2017_
    - o Extraordinary Coursework: Biomechanics, Vestibular Rehab, Manual Therapy, Pain Science, Wound Care
- ❖ Bachelor of Science in Human Biology. University of California, San Diego (UCSD). San Diego, CA. June 2012.

Clinical Experience

- ❖ FYZICAL Sports Physical Therapy: Las Vegas, Nevada. January-March 2017.
    - o Clinical internship
    - o Outpatient orthopedic physical therapy
- ❖ Veterans Affairs – Southern Nevada Healthcare System: Las Vegas, Nevada. October 2016-January 2017.
    - o Clinical internship
    - o Acute-underserved physical therapy
- ❖ HealthSouth Rehabilitation Hospital-Desert Canyon: Las Vegas, Nevada. July-August 2016, April-May 2017.
    - o Clinical internship
    - o Inpatient rehabilitation physical therapy
- ❖ Family and Sports Physical Therapy: Las Vegas, Nevada. June-August 2015.
    - o Clinical internship
    - o Outpatient orthopedic physical therapy

Continuing/Supplemental Education

- ❖ Pain Seminar: Dr. Adriaan Louw. April 2016.
- ❖ APTA Combined Sections Meeting: Anaheim, CA. February 2016.
- ❖ UNLVPT Distinguished Lecture Series: Shaw Bronner, PT, PhD, OCS--"So you want to treat dancers?" November 2015
- ❖ APTA course: Interpreting the Electrocardiogram. September 2015.
- ❖ UNLV Physical Therapy Graduate School Class of 2015 Thesis Presentations. May 2015.
- ❖ Pain Seminar: Dr. Adriaan Louw. April 2015.
- ❖ APTA lecture: Dr. McGee—New and controversial anterolateral ligament of the knee. April 2015.
- ❖ HIPAA Basics Training Completion. March 2015
- ❖ UNLVPT Distinguished Lecture Series: Timothy Flynn, PT, PhD—"America is in Pain—Physical Therapy Solution." November 2014.

Professional Association Membership

- American Physical Therapy Association (APTA) member since 2014.
- Nevada Physical Therapy Association (NPTA) member since 2014.
- American Heart Association Healthcare Provider CPR and AED Certification since April 2015.
    - Expires in April 2017

Research Experience

- Personal Doctoral Research. Defense Date May 2017.
    - Manzanares R, Popescu L. Use of Active Video Gaming in Children with Neuromotor Dysfunction: A Systematic Review.

Professional Leadership

- UNLV Class of 2017 Class Vice President. 2014-2015.

Scholarships and Awards

- UNLVPT Student Opportunity Research Grant awarded 2015.
    - Manzanares R, Popescu L. Use of Active Video Gaming in Children with Neuromotor Dysfunction: A Systematic Review.
- UNLVPT Scholars Award. February 2014.
- Magna Cum Laude. University of California, San Diego. June 2012.