ISSN: 2469-5718

International Journal of
Sports and Exercise Medicine

Research Article: Open Access

Exergaming to Improve Physical and Mental Fitness in Children and Adolescents with Autism Spectrum Disorders: Pilot Study

Claudia L. Hilton[1]*, Allison Attal[2], John R. Best[3], Timothy A. Reistetter[1], Pete Trapani[4] and Diane M. Collins[1]

[1]*Occupational Therapy & Rehabilitation Sciences Departments, University of Texas Medical Branch, USA*

[2]*Occupational Therapy Department, University of Texas Medical Branch, USA*

[3]*Djavad Mowafaghian Centre for Brain Health, University of British Columbia, USA*

[4]*Fitness for Life & Health, USA*

***Corresponding author:** *Claudia L. Hilton, University of Texas Medical Branch, Occupational Therapy & Rehabilitation Sciences Departments, School of Health Professions, 301 University Blvd, Galveston, TX 77555-1142, USA, Tel: 409-772-3079, Fax: 409-747-1615, E-mail: clhilton@utmb.edu*

Abstract

Although not included as core characteristics of autism spectrum disorders (ASD), children and adolescents with this diagnosis often experience executive function (EF) and motor impairments. This study investigated the use of a speed-based exergame called the Makoto arena as an intervention strategy to improve EF and motor performance in in 17 school-aged children and adolescents with ASD. All areas of EF improved, with significance in the overall *global executive composite* and in the *metacognition index* of the Behavior Rating Inventory of Executive Function. All motor skills improved except *fine manual coordination*, with significance in *strength and agility* on the Bruininks-Oseretsky Test of Motor Proficiency, 2nd Edition. Participants increased response speed showing a large effect size. Findings suggest that use of exergaming may be a beneficial addition to be included in interventions for children and adolescents with ASD who experience impairments in EF and motor performance.

Keywords

Active video games, Autism spectrum disorders, Executive function, Exergames, Motor skills

Upon reaching adulthood, an alarmingly low percentage of individuals with autism spectrum disorders (ASD) are employed, get married, or achieve enough independence to live alone [1-3]. These problems reflect an important societal need, are important to clients, families, practitioners, and policy makers, and need to be better addressed during childhood and adolescence. Many of these issues are related to impairments in executive function (EF); [4-6] and motor skills [7]. EF contributes to success in school [8,9] and work [5,6] allows people to manage the stresses of and barriers to daily life activities [4]. Poor motor skills limit participation in many important life activities. Although not included in the diagnostic criteria [10], impairments in EF [11-13] and motor skills [14-18] have been consistently observed in individuals diagnosed with ASD.

Executive Function

EF refers to higher order cognitive processes that are used to guide behavior in a changing environment, and includes the constructs of planning, inhibition, impulse control, working memory, cognitive flexibility, creativity, and initiation of action [19]. EF includes the skills necessary for goal-directed cognition and purposeful activity [20]. EF is also important for being able to inhibit inappropriate behaviors [6]. Without good EF, children and adults may say or do things that are considered to be bizarre or offensive, thus impeding positive social interactions. These skills are also needed in various circumstances, including self-directed learning and emotional regulation, which can contribute to academic success in children [21], and successful participation in adult roles [4]. Deficits in aspects of EF have been replicated by numerous studies of children with ASD [12,13].

Motor Impairment

Motor skills are necessary for many types of human activities, such as self-care, writing, games, sports, dance and recreational activities [22-24]. Motor impairment is recognized as a symptom associated with ASD by the World Health Organization [25]. Motor deficits often associated with ASD may include problems in motor planning, coordination, and an inability to participate in developmentally appropriate activities, which affect the child's ability to initiate motor activities or switch between motor tasks [15,16,26-28].

Motor impairment has been demonstrated in many studies of children with ASD. Several studies have found that approximately 80%- 90% of persons with ASD who were study participants demonstrated some degree of motor impairment such as fine and gross motor planning or coordination challenges, strength or agility problems, dyspraxia, and neurological signs of dysrhythmia, abnormal muscle tone, praxis, and motor impersistence [14-17].

Citation: Hilton CL, Attal A, Best JR, Reistetter TA, Trapani P, et al. (2015) Exergaming to Improve Physical and Mental Fitness in Children and Adolescents with Autism Spectrum Disorders: Pilot Study. Int J Sports Exerc Med 1:017

Received: April 30, 2015: **Accepted:** August 15, 2015: **Published:** August 18, 2015

Motor impairment has been linked to specific functional skills in children with ASD. Linkenauger, Lemer, Ramenzoni and Proffitt [29] found that, compared with controls, individuals with ASD showed gross motor impairments in relating information about their bodies' action capabilities to visual information specifying the environment and that the magnitude of these deficits strongly predicted the magnitude of social/communicative impairments in those individuals with ASD. They concluded that social/communicative impairments in ASD may derive, at least in part, from motor deficits. In another study, MacDonald, Lord, & Ulrich [30] determined that fine motor performance skills were predictive of adaptive behavior skill performance ($p<0.01$), while gross motor performance skills were predictive of daily living skill performance ($p<0.05$). The authors later determined that greater motor deficits predicted greater deficits in adaptive behavior skills [31].

Relationship between Executive Function and Comorbidities

Several studies have shown that EF has a crucial relationship with other autistic comorbidities. Links between EF and repetitive behaviors [32], anxiety [33], and comorbid psychopathology [34] have been identified in children with ASD. Lopez and colleagues [32] compared 17 adults with ASD and 17 controls and found that the occurrence of repetitive behaviors in the group with ASD was strongly correlated with cognitive flexibility, working memory, and response inhibition, all aspects of EF. They postulated that when individuals with ASD experience executive dysfunction, it impairs the ability to produce, plan, and manage behaviors, which results in the atypical behavior associated with ASD. Because engagement in repetitive behaviors acts as a barrier to social and community participation and integration, these results suggest that interventions which improve EF could also have the added positive effect of decreasing repetitive behaviors [35]. Hollocks and associates [33] examined 90 adolescents with ASD between 14 and 16 years of age and found a significant association between poorer executive functioning and higher levels of anxiety. Findings from a study of 70 children and adolescents between age 6 and 16 years diagnosed with ASD by Lawson and associates [34] indicate EF problems as a predictor of comorbid psychopathology (anxiety/depression and aggression/oppositionality) and as crucial intervention targets for potential prevention and mitigation of comorbid symptoms. EF and motor impairment in children may also be related. Studies of typically developing children suggest that EF and motor performance have underlying processes in common that relate to planning, monitoring, and detecting and correcting errors [36-40]. Hartmann, Houwen, & Visscher [41] found that children with intellectual disabilities experience difficulty with EF and motor performance, specifically object control skills, and that EF and motor performance were positively correlated.

Exercise and Cognition in Children with ASD

Physical exercise has been found to improve cognitive processes, specifically EF, in typically developing individuals [42-44]. Likewise, it has been found to have a positive influence on symptoms seen in children and adolescents with ASD, including improvement in EF and a reduction in repetitive behaviors [45-48]. The mechanism of improvement in these cognitive functions as a result of physical exercise is only partially understood, and is thought to be caused by increased cerebral blood flow, up-regulation of neuroprotective growth factors, and the cardiovascular benefits of exercise, which lead to an improvement in the delivery of oxygen and nutrients [43,48].

Children with ASD often participate in limited physical activities [49] enjoy them less than do typically developing children [50] experience weight gain from medications [51] and encounter problems with reduced physical fitness and obesity [52]. Lack of interest or motivation to exercise may make it difficult for them to comply with daily physical activity recommendations [53].

The use of virtual reality electronic games that combine physical activity and play, known as exergames or active video games, has been found to be an effective intervention to increase cognitive capabilities and to enhance body movement and energy expenditure in healthy individuals [20,54-57].

Several studies have found the use of exergames to have beneficial effects on cognitive performance in children with ASD. Anderson-Hanley et al. [58] found an improvement in behavioral and cognitive performance, specifically a decrease in repetitive behavior and an increase in EF, after participation in an exergame intervention called *Dance Dance Revolution* by 12 school-aged children with ASD. Similarly, Hilton et al. [45] examining earlier pilot data from the current study, found an improvement in the EF areas of working memory and metacognition, the motor areas of strength and agility, and response speed, in children with ASD following participation in the Makoto arena, an exergaming intervention. These findings suggest that the use of exergaming has the potential to be an effective intervention tool to improve EF and motor functioning in children with ASD.

Other studies investigating the use of exergames as intervention tools in children with other conditions have found positive results as well. A study investigating the effects of Wii® interactive games on sensorimotor function in children with Down syndrome found an improvement in motor proficiency, visual integration skills, and sensory integrative functions [59]. In addition, Sandlund et al. [60] found an increase in physical activity participation and motor performance in children with cerebral palsy following a PlayStation2® exergame. These findings provide evidence to suggest that motion-interactive videogames may help to improve functioning in children with various conditions and could lead to an enhanced quality of life. However, review of literature done by Best [61] identified only 2 studies in typically developing youth [20,62]and one study in children with developmental disorders [58] that examined the utility of exergaming in improving cognitive function in youth; further research is needed to study the short and long-term influences of exergaming on cognition, specifically EF, in children.

This study aimed to investigate whether EF, motor skills, and response speed in children and adolescents with ASD, aged 8 to 18 years of age, would be positively affected by participating in 30 or more Makoto arena sessions. Developed as a motor response speed game, the Makoto training arena was initially used in sports, schools, and medical rehabilitation to improve response speed, attention and physical fitness of participants (Makoto, USA, Inc., n.d.). [63]. The Makoto arena consists of three 6-foot tall towers, spaced 6 feet apart in a triangular configuration. Each of the three towers has 10 lights, which illuminate with an associated tone in random order. Lower tones signify that the illuminated light is near the bottom of a tower, while higher tones indicate a location near the top. Different speed progressions and games are offered, with the goal of being able to identify and tap the light as rapidly as possible before the allocated time expires. Measuring overall accuracy and response speed, the Makoto device also provides instant auditory reinforcement.

The current study combines novel data with data collected from our previous pilot study [45] to address the following research questions: 1) Does participation in the Makoto arena as an OT intervention improve EF among school-aged, high-functioning children on the autism spectrum? 2) Does participation in the Makoto arena intervention positively affect motor skills and performance among school-aged, high-functioning children on the autism spectrum? and 3) Does participation in the Makoto arena result in improved response speeds among school-aged, high-functioning children on the autism spectrum?

Method

Research design

Using a repeated-measures study, we compared pre-intervention assessments with post-intervention assessments to determine whether these outcomes were affected by the Makoto arena intervention. IRB approval was obtained prior to data collection.

ISSN: 2469-5718

Participants

Study participants were high functioning children and adolescents with ASD, between the ages of 8 and 18 years, who were recruited from two schools that provided services for children and adolescents with ASD. One school was a public school and the other was private. In comparing the students who went to the private school versus the public school, no demographic or socioeconomic differences were observed. Additional study participants were recruited through a parent network comprised of families having children with ASD in the St. Louis, MO, greater metropolitan area. Inclusion criteria were having been diagnosed with ASD, an IQ score of 65 or higher, and a willingness on the part of the child to participate in the Makoto intervention for approximately 3 times per week. Students with IQs lower than 65 were excluded from the study. Our concern was that students with IQs lower than 65 might serve as potential confounders of the study outcome of EF. For students without available IQ scores, researchers administered the Wechsler Abbreviated Scale of Intelligence [64]. Additional exclusion criteria included students with sensory impairments or behavioral problems who would be unable to see or hear the cues provided by the Makoto arena intervention, or those children and adolescents who were unable or unwilling to follow the directions of the researchers. The ASD diagnosis of study participants was made by an experienced clinician following the criteria of the fourth edition, text revision, of the DSM [65].

Measures

Study participants were evaluated before and after intervention with the Bruininks-Oseretsky Test of Motor Proficiency, 2nd Edition (BOT–2) [66] and the Behavior Rating Inventory of Executive Function [67]. During each Makoto arena session, the average reaction speed of each study participant was recorded.

The Bruininks-Oseretsky Test of Motor Proficiency, 2nd Edition (BOT–2) [66] was used to assess motor proficiency, which includes *fine motor coordination and integration*, *manual coordination* (manual dexterity and upper extremity coordination), bilateral *body coordination* and balance, and *strength and agility*. Gender- and age-specific standard subscale scores are generated, as is a *total motor composite score,* which have been normed for participants between ages 4 and 21 years. For this study, all BOT–2 assessments interrater reliability at the item level was >90% before scoring the assessments. Greater motor performance is correlated with higher scores on the BOT–2. The BOT–2 has strong internal subtest consistency (0.71–0.95), internal composite consistency (0.93-0.97), test– retest reliability (0.48–0.94), and interrater reliability (0.92–0.99) [66]. Good content and construct validity have been established for this instrument.

The BRIEF [67] was used to assess the behavioral and cognitive characteristics of EF with a standardized 86-item, parent-report questionnaire. Higher BRIEF scores indicate greater EF impairment and the instrument is standardized for age and gender. BRIEF t-scores of greater than 65 indicate executive impairments. The BRIEF is comprised of two indices, *behavioral regulation* (modulations of emotions and behavior) and *metacognition* (ability to initiate, plan, organize, and sustain future-oriented problem solving in working memory), and one *global executive composite* summary score. Internal consistency of the BRIEF is strong (0.82–0.98) as is test–retest reliability (0.72–0.83) [67]. Content and construct validity for this assessment are good and moderate inter-rater reliability (overall mean r = 0.32) have been established.

Behavioral regulation components of the BRIEF include *inhibit* (not acting on impulse), *shift* (transferring without difficulty from one situation to another), and *emotional control* (ability to temper emotional reactions). Components of metacognition include *initiate* (beginning a task or generating ideas), *working memory* (ability to hold information in memory for task completion), *plan/organize* (ability to balance and handle different task demands), *organization of materials* (orderliness of spaces in which the child works and plays), and *monitor* (observe and adjust on-task habits).

The Makoto arena provides average response time and accuracy information for each session played. Accuracy measures the percentage of times the participant hits the target within the time limit set by the speed level. Before each speed level increase, the participant needed to attain at least 95% accuracy.

Participants were also asked a group of questions after completing the protocol indicating how much they enjoyed participating in the game, if they thought it helped them get better at other things, and if they were glad to have participated in the study. Answer choices were a Likert scale (1 = not at all, 2 = a little, 3 = somewhat/sort of, 4 = pretty much, 5 = very much).

Intervention

Participants were allowed choices on the frequency of the intervention. They usually completed up to three 2-minute Makoto arena sessions in a row each day with rest periods between, and up to 6 sessions per week, with a total average duration of 8 weeks, with a range of 6 to 10 weeks, to complete the 30 sessions. Response speed was generated from approximately 1,800 attempts to hit the Makoto arena targets during the 30 sessions. We began each participant at the slowest speed and we increased to the next faster speed each time they mastered the previous speed level by at least 95%. The levels were set at: 3 seconds (s), 2.5 s, 2.25 s, 2.0 s, 1.75 s, 1.5 s, 1.3 s, 1.17 s, 1.04 s, 1.0 s, and 0.95 s.

Procedures

After training, graduate students or the principle investigator administered the assessments and interventions in quiet rooms with limited distractions at the Clayton Child Center, Edgewood Center, and Washington University School of Medicine in St. Louis, Missouri. We conducted the interventions within one month of pretesting for each child and we completed post-testing within one month of completion of the intervention. To assure safety, participants were required to wear stable shoes, such as athletic shoes, while engaging in the Makoto arena. All participants were either at a school with a school nurse available or accompanied by a parent in case they might be injured during participation in the game.

Statistical analyses

The IBM SPSS Statistics 20 (IBM Corporation, Armonk, NY) was used for data analysis. Nonparametric measures were used to analyze the BRIEF and BOT–2 data because of the small sample size and skewed distributions in two of the motor variables. We compared standardized scores with test norms and examined Spearman rho correlation coefficients between EF and motor subscale standardized scores for pretests. Standardized scores for pre- and post-tests were compared and analyzed by using paired Wilcoxon signed rank tests to detect significant effects related to the intervention. We analyzed reaction speeds between Sessions 6 and 30, allowing five practice trials for each child before scores were included in the analyses, using paired Wilcoxon signed rank tests to determine significant changes. Additionally, we calculated standardized effect sizes using standard approaches (0.10-0.24 = small, 0.25-0.39 = medium, >0.40 = large; [68,69] for the pretest–posttest scores. Effect size calculations for non-parametric data analyses followed the method used by Weberg, Hjermstad, Hilmarsen, and Oldervoll [70]. The *p* value for significance was set at $p < 0.05$.

Results

Recruitment produced 18 participants with ASD for study enrollment. One child was discontinued from the study because he would not follow the Makoto study protocol and baseline data collection was not possible to complete. The remaining 17 participants completed the protocol. Four of the parents did not return the BRIEF post-test forms so those were not included in the analyses. Participants were between 8 and 18 years of age (mean = 11.76) at the time intervention began with 12 males and 5 females. Participants had occasional falls while engaged in the intervention, but none involved any sustained injuries. Full-scale IQs ranged from 66 to 136 (mean =

93.82), verbal from 63 to 151 (mean = 98.18), performance from 58 to 143 (mean = 90.06). Participant family income was reported as less than $30,000 per year (3 families), $31,000 to 75,000 (4), $76,000 to 110,000 (5), $111,000 to 250,000 (1), more than $250,000 (1) and not reported (3).

Standardized scores for BRIEF pretesting indicated that the *behavioral regulation* and *metacognition* indexes; and the *global executive composite* were all >65, indicating clinically significant impairments in these areas. Standardized BOT–2 scores for *manual coordination and strength and agility* were <40, indicating impairment in these areas. See table 1 for details.

Pretest total motor scores were negatively correlated with EF *metacognition index* (r = -0.57, p = 0.016), and the EF *global executive composite* (r = -0.55, p = 0.023). Pretest *manual coordination* scores were negatively correlated with the EF *metacognition index* (r = -0.50, p = 0.043).

Mean speeds from the sixth and last (30th) Makoto arena intervention sessions were compared. Participants' response speed increased resulting in a large effect size of -0.62 [69]. See table 2 for details. We compared the means of pretest and post-test scores for the BRIEF and BOT–2. Improvement was observed in all areas of the BRIEF and in all except *fine manual control* of the BOT-2. Because of the small sample size, effect size was considered to be a more valid measure than significance levels. Large effect sizes were observed in the *global executive composite* and both the *behavioral and metacognition indices* of the BRIEF. The BRIEF overall score, the *global executive composite*, showed a significant improvement (p = 0.016). The *metacognition index* change, which indicates general improvement in the ability to initiate, plan, organize, and sustain future-oriented problem solving in working memory, was significant (p = 0.005). The *behavioral regulation index*, which represents a child's ability to shift cognitive set and modulate emotions and behavior via appropriate inhibitory control, showed a large effect size, but was not significant. See table 3 for details. BOT-2 t scores showed significant improvement only in the motor area of strength and agility (p = 0.002), which showed a large effect size (r = 0.54). See table 3 for details.

Answers to questionnaires showed that 88% of participants experienced some degree of enjoyment from playing the Makoto games, 82% felt like they improved in other areas outside of the game, and 82% were glad that they participated in the study. Other areas that were identified as improved included *sports, gym, running, speed, coordination, having a little fun, focus better in class, the way I look at life, school*, and *my anger issues at home.*

Table 1: Executive Function and Motor Impairments of Participants

Category	*Percent Impaired Pre	*Percent Impaired Post
BRIEF		
Behavior Regulation Index	71	54
Metacognition Index	71	62
Global Executive Composite	71	46
BOT2		
Fine Manual Control	53	59
Manual Coordination	65	59
Body Coordination	53	47
Strength & Agility	65	42
Total Motor Composite	76	59

*Percent Impaired indicates % of participants with a score considered to have potential clinical significance (t score >65 for BRIEF, t score < 40 for BOT-2). BOT-2: Bruininks-Oseretsky Test of Motor Proficiency- Second Edition, BRIEF: Behavior Rating Inventory of Executive Function.

Table 2: Pre & Post Intervention Executive Function Scores (n = 13)

BRIEF t score (mean = 50, SD = 10)	Median Pre	Median Post	Z-score	Effect size (r)
Behavioral Regulation Index	77	69	-1.51	-0.50
Metacognition Index	72	66**	-2.81	-0.55
Global Executive Composite	75	64.5*	-2.40	-0.47

* p < 0.05, **p < 0.01, BOT-2: Bruininks-Oseretsky Test of Motor Proficiency- Second Edition, BRIEF: Behavior Rating Inventory of Executive Function. Lower scores represent better functioning.

Discussion

Findings from this study corroborate previous studies, which found motor impairment [11,14-18] and EF impairment [12,13] in children with ASD. They also suggest that the relationship between motor performance and EF observed in typically developing children [36-40] and those with intellectual disability [41] may also exist in children with ASD.

Improvements seen in this study in reaction speed, EF, and motor performance after participation in the Makoto arena intervention support previous findings from use of the Makoto arena [45]. They also support previous studies that found physical exercise to improve cognitive processes in children and adolescents with ASD [46,47]. Significant improvement in EF in the entire section of *metacognition*, beyond the single subtest of *working memory*, strengthens and expands previous findings from Hilton et al. [45]. These changes may arise from increased cerebral blood flow, which leads to an improvement in the delivery of oxygen and nutrients to the brain [43,48] Changes may also be attributed to generalization of skills learned through the intervention. For example, the game requires cognitive flexibility and inhibition of prepotent responses in order to respond to new stimuli. These learned skills may generalize beyond the game context, as captured by improvements on the BRIEF. The repeated demands of rigorously moving their whole bodies to increase speed in hitting the targets is likely the reason for improvement in strength and agility as captured by improvements in the BOT-2. The participants' reports of improvements in other areas of their lives suggest the possibility of more generalizable improvement effects.

The fact that all of the qualified participants who began the study and were willing to follow the protocol did complete the entire sequence of the intervention indicates their willingness to participate in this type of substantial physical activity. Interest and motivation to participate seemed to carry them to completion of the protocol, even though some reported not enjoying it. The formal structure of the protocol of this exergame qualifies it as being a formal activity. Formal activities showed more diverse participation among children with ASD, more similar to typically developing children, in a prior study [49]. This suggests that participation in this type of formal physical activity may be helpful in motivating children and adolescents with ASD to comply with daily physical activity recommendations to help deal with common problems of weight gain from medications and reduced physical fitness and obesity experienced by this population [51-53].

Table 3: Pre & Post Intervention Motor Scores (n = 17)

Test	Median Pre	Median Post	Z-score	Effect Size (r)
BOT-2 Standard Scores (mean = 50, SD = 10)				
Fine Manual Control	39	38	-.086	0
Manual Coordination	34	39	-1.72	0.29
Body Coordination	36	40	-.87	0.15
Strength and Agility	38	40*	-3.17	0.54
Makoto Response Speed (seconds)				
Session 6 & Session 30	1.46	1.18**	-3.62	-0.62

* p < 0.05, **p < 0.01, BOT-2: Bruininks-Oseretsky Test of Motor Proficiency- Second Edition, BRIEF: Behavior Rating Inventory of Executive Function.

This study is limited by its small sample size and lack of a randomized control group. Lack of a control group does not allow for comparison of the experimental group to the improvements that might be seen through normal development and familiarity with the assessments, although each test is standardized for age and gender. In addition, use of subjects as their own controls in a repeated measures study such as this one has potential merit as a small *n* study in the rehabilitation field [71]. Portney and Watkins [72] indicate the major advantage of this design as "the ability to control for the potential influence of individual differences." The range in length of time to complete the intervention was also a limitation, since it varied as much as two months among participants. Another limitation of this study is that this particular exergame is expensive for individual families and is best used in a school, therapy center or community recreation center. Scientific rigor could be increased by adding a randomized controlled trial with a larger cohort and including an observation-based measure of EF. Adding a measure to examine maintenance of improvements would also add to the value of these findings and strengthen their generalizability. Additional research should be conducted to replicate and extend these findings, to examine dosage and alternative exergames, to clarify exergaming components that may influence cognitive and motor outcomes, and to examine the long-term and applied utility of exergaming for ASD. Additional work is also needed to examine the effects on children who are not defined as high functioning, who might, indeed, benefit from this type of intervention.

Conclusion

It is important to identify effective, interesting, and motivating interventions to be able to provide the optimal impact through therapy for children and adolescents with ASD. The findings from this study suggest that the use of exergaming, specifically the Makoto arena, may be useful for improving EF and motor skills in children and adolescents with ASD, although further examination of dosage, alternative exergames, long-term effects, and specific effects on school performance are warranted. Significant correlations between certain EF and motor scores suggest a relationship between the two constructs. Continued work addressing this line of inquiry to further understand and possibly increase the benefits of various types of exergaming for people with ASD will be helpful to inform best practice.

Acknowledgements

This study was partially funded by Washington University School of Medicine, Program in Occupational Therapy. The authors would like to thank the participants and their families, the Clayton Child Center, and the education director, Kelly McCrary, the teachers and the staff at Edgewood Children's Center. They would also like to thank Shannon Gaetke, Sarah Dugan, Alisha Munoz, Ben Olch, Kristin Seefeldt, Caitlin Stockelman, Stephanie Zaepfel, Amanda Artner, Kristina Cumpata, Lisa Colton, Sarah Dobbs, Hailey Johnson, Jill Phillips, Kelly Schwieterman, Sophie Goloff, Andrea Bennett, Ashlyn Hudson and Danielle Vest for their help with testing, scoring, and data entry.

References

1. Farley MA, McMahon WM, Fombonne E, Jenson WR, Miller J, et al. (2009) Twenty-year outcome for individuals with autism and average or near-average cognitive abilities. Autism Res 2: 109-118.
2. Howlin P, Mawhood L, Rutter M (2000) Autism and developmental receptive language disorder--a follow-up comparison in early adult life. II: Social, behavioural, and psychiatric outcomes. J Child Psychol Psychiatry 41: 561-578.
3. Mordre M, Groholt B, Knudsen AK, Sponheim E, Mykletun A, et al. (2012) Is Long-Term Prognosis for Pervasive Developmental Disorder Not Otherwise Specified Different from Prognosis for Autistic Disorder? Findings from a 30-Year Follow-Up Study. J Autism Dev Disord 42: 920-928.
4. Dawson EL, Shear PK, Strakowski SM (2012) Behavior regulation and mood predict social functioning among healthy young adults. J Clin Exp Neuropsychol 34: 297-305.
5. Fergusson DM, Boden JM, Horwood LJ (2013) Childhood self-control and adult outcomes: results from a 30-year longitudinal study. J Am Acad Child Adolesc Psychiatry 52: 709-717.
6. Miller M, Nevado-Montenegro AJ, Hinshaw SP (2012) Childhood Executive Function Continues to Predict Outcomes in Young Adult Females with and Without Childhood-Diagnosed ADHD. J Abnorm Child Psychol 40: 657-668.
7. Lloyd M, Saunders TJ, Bremer E, Tremblay MS (2014) Long-term importance of fundamental motor skills: a 20-year follow-up study. Adapt Phys Activ Q 31: 67-78.
8. Chiang HL, Gau SS (2014) Impact of executive functions on school and peer functions in youths with ADHD. Res Dev Disabil 35: 963-972.
9. van der Donk ML, Hiemstra-Beernink AC, Tjeenk-Kalff AC, van der Leij AV, Lindauer RJ (2013) Interventions to improve executive functioning and working memory in school-aged children with AD(H)D: a randomised controlled trial and stepped-care approach. BMC Psychiatry 13: 23.
10. American Psychiatric Association (2013) Diagnostic and statistical manual of mental disorders 5th ed., text rev). Washington, DC.
11. Robinson S, Goddard L, Dritschel B, Wisley M, Howlin P (2009) Executive functions in children with autism spectrum disorders. Brain Cogn 71: 362-368.
12. Pellicano E (2007) Links between theory of mind and executive function in young children with autism: clues to developmental primacy. Dev Psychol 43: 974-990.
13. Pellicano E, Maybery M, Durkin K, Maley A (2006). Multiple cognitive capabilities/deficits in children with an autism spectrum disorder: "Weak" central coherence and its relationship to theory of mind and executive control. Dev Psychopathol 18: 77-98.
14. David FJ, Baranek GT, Giuliani CA, Mercer VS, Poe MD, et al. (2009) A pilot study: coordination of precision grip in children and adolescents with high functioning autism. Pediatr Phys Ther 21: 205-211.
15. Dziuk MA, Gidley Larson JC, Apostu A, Mahone EM, Denckla MB, et al. (2007) Dyspraxia in autism: association with motor, social, and communicative deficits. Dev Med Child Neurol 49: 734-739.
16. Hilton CL, Zhang Y, Whilte MR, Klohr CL, Constantino J (2012) Motor impairment in sibling pairs concordant and discordant for autism spectrum disorders. Autism 16: 430-441.
17. Ming X, Brimacombe M, Wagner GC (2007) Prevalence of motor impairment in autism spectrum disorders. Brain Dev 29: 565-570.
18. Provost B, Lopez BR, Heimerl S (2007) A comparison of motor delays in young children: autism spectrum disorder, developmental delay, and developmental concerns. J Autism Dev Disord 37: 321-328.
19. Sachse M, Schlitt S, Hainz D, Ciaramidaro A, Schirman S, et al. (2013) Executive and visuo-motor function in adolescents and adults with autism spectrum disorder. J Autism Dev Disord 43: 1222-1235.
20. Best JR (2012) Exergaming immediately enhances children's executive function. Dev Psychol 48: 1501-1510.
21. Blair C, Diamond A (2008) Biological processes in prevention and intervention: the promotion of self-regulation as a means of preventing school failure. Dev Psychopathol 20: 899-911.
22. Clark JE, Metcalfe JS (2002) The mountain of motor development: A metaphor. In Clark JE, Humphrey JH. Motor development: Research and reviews. Reston, VA: National Association of Sport and Physical Education.
23. Lubans DR, Morgan PJ, Cliff DP, Barnett LM, Okely AD (2010) Fundamental movement skills in children and adolescents: review of associated health benefits. Sports Med 40: 1019-1035.
24. Stodden DF, Goodway JD, Langendorfer SJ, Roberton MA, Rudisill ME, et al. (2008) A developmental perspective on the role of motor skill competence in physical activity: An emergent relationship. Quest 60: 290-306.
25. World Health Organization (2001) International classification of functioning, disability and health. Geneva.
26. Abu-Dahab S, Skidmore E, Holm M, Rogers J, Minshew N (2013) Motor and tactile-perceptual skill differences between individuals with high functioning autism and typically-developing individuals ages 5-21 J Autism Dev Disord 43: 2241-2248.
27. Lloyd M, MacDonald M, Lord C (2013) Motor skills of toddlers with autism spectrum disorders. Autism 17: 133-146.
28. Wiggins LD, Robins DL, Bakeman R, Adamson LB (2009) Brief report: sensory abnormalities as distinguishing symptoms of autism spectrum disorders in young children. J Autism Dev Disord 39: 1087-1091.
29. Linkenauger SA, Lerner MD, Ramenzoni VC, Proffitt DR (2012) A perceptual-motor deficit predicts social and communicative impairments in individuals with autism spectrum disorders. Autism Res 5: 352-362.
30. MacDonald M, Lord C, Ulrich D (2013) The relationship of motor skills and adaptive behavior skills in young children with autism spectrum disorders. Res Autism Spectr Disord 7: 1383-1390.
31. MacDonald M, Lord C, Ulrich DA (2014) Motor skills and calibrated autism severity in young children with autism spectrum disorder. Adapt Phys Activ Q 31: 95-105.
32. Lopez BR, Lincoln AJ, Ozonoff S, Lai Z (2005) Examining the relationship between executive functions and restricted, repetitive symptoms of Autistic Disorder. J Autism Dev Disord 35: 445-460.

33. Hollocks MJ, Jones CR, Pickles A, Baird G, Happé F, et al. (2014) The association between social cognition and executive functioning and symptoms of anxiety and depression in adolescents with autism spectrum disorders. Autism Res 7: 216-228.

34. Lawson RA, Papadakis AA, Higginson CI, Barnett JE, Wills MC et al. (2015). Everyday executive function impairments predict comorbid psychopathology in autism spectrum and attention deficit hyperactivity disorders. Neuropsychology 29: 445-453.

35. Lord CE1 (2010) Autism: from research to practice. Am Psychol 65: 815-826.

36. Best JR, Miller PH, Jones LL (2009) Executive Functions after Age 5: Changes and Correlates. Dev Rev 29: 180-200.

37. Livesey D, Keen J, Rouse J, White F (2006) The relationship between measures of executive function, motor performance and externalising behaviour in 5- and 6-year-old children. Hum Mov Sci 25: 50-64.

38. Piek JP, Dyck MJ, Nieman A, Anderson M, Hay D, et al. (2004) The relationship between motor coordination, executive functioning and attention in school aged children. Arch Clin Neuropsychol 19: 1063-1076.

39. Roebers CM, Kauer M (2009) Motor and cognitive control in a normative sample of 7-year-olds. Dev Sci 12: 175-181.

40. Wassenberg R, Feron FJ, Kessels AG, Hendriksen JG, Kalff AC, et al. (2005) Relation between cognitive and motor performance in 5- to 6-year-old children: results from a large-scale cross-sectional study. Child Dev 76: 1092-1103.

41. Hartman E, Houwen S, Scherder E, Visscher C (2010) On the relationship between motor performance and executive functioning in children with intellectual disabilities. J Intellect Disabil Res 54: 468-477.

42. Brisswalter J, Collardeau M, René A (2002) Effects of acute physical exercise characteristics on cognitive performance. Sports Med 32: 555-566.

43. Colcombe S, Kramer AF (2003) Fitness effects on the cognitive function of older adults: a meta-analytic study. Psychol Sci 14: 125-130.

44. Hillman CH, Belopolsky AV, Snook EM, Kramer AF, McAuley E (2004) Physical activity and executive control: implications for increased cognitive health during older adulthood. Res Q Exerc Sport 75: 176-185.

45. Hilton CL, Cumpata K, Klohr C, Gaetke S, Artner A, et al. (2014) Effects of exergaming on executive function and motor skills in children with autism spectrum disorder: a pilot study. Am J Occup Ther 68: 57-65.

46. Lang R, Koegel L, Ashbaugh K., Regester A, Ence W, et al. (2010) Physical exercise and individuals with autism spectrum disorders: A systematic review. Research in Autism Spectrum Disorders 4: 565-576.

47. Petrus C, Adamson SR, Block L, Einarson SJ, Sharifnejad M, et al. (2008) Effects of exercise interventions on stereotypic behaviours in children with autism spectrum disorder. Physiother Can 60: 134-145.

48. Cotman CW, Berchtold NC, Christie LA (2007) Exercise builds brain health: key roles of growth factor cascades and inflammation. Trends Neurosci 30: 464-472.

49. Hilton CL, Crouch MC, Israel H (2008) Out-of-school participation patterns in children with high-functioning autism spectrum disorders. Am J Occup Ther 62: 554-563.

50. Eversole M, Collins DM, Karmarkar A, Colton L, Quinn JP, et al. (2015) Leisure Activity Enjoyment of Children with Autism Spectrum Disorders. J Autism Dev Disord .

51. Hellings JA, Zarcone JR, Crandall K, Wallace D, Schroeder SR (2001) Weight gain in a controlled study of risperidone in children, adolescents and adults with mental retardation and autism. J Child Adolesc Psychopharmacol 11: 229-238.

52. Egan AM, Dreyer ML, Odar CC, Beckwith M, Garrison CB (2013) Obesity in young children with autism spectrum disorders: prevalence and associated factors. Child Obes 9: 125-131.

53. O’Connor J, French R, Henderson H (2000) Use of physical activity to improve behavior of children with autism-Two for one benefits. Palestra 16: 22-27.

54. Graves L, Stratton G, Ridgers ND, Cable NT (2008) Energy expenditure in adolescents playing new generation computer games. Br J Sports Med 42: 592-594.

55. Lanningham-Foster L, Foster RC, McCrady SK, Jensen TB, Mitre N, et al. (2009) Activity-promoting video games and increased energy expenditure. J Pediatr 154: 819-823.

56. Penko AL, Barkley JE (2010) Motivation and physiologic responses of playing a physically interactive video game relative to a sedentary alternative in children. Ann Behav Med 39: 162-169.

57. Worley JR, Rogers SN, Kraemer RR (2011) Metabolic responses to Wii Fitâ„¢ video games at different game levels. J Strength Cond Res 25: 689-693.

58. Anderson-Hanley C, Tureck K, Schneiderman RL (2011) Autism and exergaming: effects on repetitive behaviors and cognition. Psychol Res Behav Manag 4: 129-137.

59. Wuang YP, Chiang CS, Su CY, Wang CC (2011) Effectiveness of virtual reality using Wii gaming technology in children with Down syndrome. Res Dev Disabil 32: 312-321.

60. Sandlund M, Waterworth EL, Häger C (2011) Using motion interactive games to promote physical activity and enhance motor performance in children with cerebral palsy. Dev Neurorehabil 14: 15-21.

61. Best JR1 (2013) Exergaming in Youth: Effects on Physical and Cognitive Health. Z Psychol 221: 72-78.

62. Staiano AE, Abraham AA, Calvert SL (2012) Competitive versus cooperative exergame play for African American adolescents’ executive function skills: Short-term effects in a long-term training intervention. Dev Psychol 48: 337-342.

63. Makoto, USA Inc. (n.d.). Makoto: We work hardest when we’re at play. Retrieved from www.makoto-usa.com

64. Wechsler D (1999) Wechsler Abbreviated Scale of Intelligence. San Antonio, TX: Pearson.

65. Lawson AK, Wright CV, Fitzgerald LF (2013) The evaluation of sexual harassment litigants: reducing discrepancies in the diagnosis of posttraumatic stress disorder. Law Hum Behav 37: 337-347.

66. Bruininks RH, Bruininks BD (2005) Bruininks-Oseretsky Test of Motor Proficiency (2nd ed.). Minneapolis, MN: Pearson Assessment.

67. Gioia, GA, Isquith PK, Guy SC, Kenworthy L (2000) BRIEF: Behavior Rating Inventory of Executive Function. Child Neuropsychol 6: 235-238.

68. Field A (2009) Discovering Statistics Using SPSS, 3rd Ed., Los Angeles: Sage.

69. Ottenbacher K, Heyn P, Abreu BC (2006) Meta-Analysis. In G. Kielhofner, Ed. Research in Occupational Therapy: Methods of Inquiry for Enhancing Practice. pp. 281-298. Philadelphia: F. A. Davis.

70. Weberg M, Hjermstad MJ, Hilmarsen CW, Oldervoll L (2013) Inpatient cardiac rehabilitation and changes in self-reported health related quality of life--a pilot study. Ann Phys Rehabil Med 56: 342-355.

71. Graham JE, Karmarkar AM, Ottenbacher KJ (2012) Small sample research designs for evidence-based rehabilitation: issues and methods. Arch Phys Med Rehabil 93: S111-116.

72. Portney LG, Watkins MP (2009) Foundations of Clinical Research: Applications to Practice (3rd ed.). Upper Saddle River, NJ: Pearson Education, Inc.

ISSN: 2469-5718