
Effects of Exergaming on Executive Function and Motor Skills in Children With Autism Spectrum Disorder: A Pilot Study

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MeSH TERMS

- child development disorders, pervasive
- exercise
- executive function
- motor skills disorders
- video games

Executive function (EF) and motor deficits have consistently been documented in studies of people with autism spectrum disorders (ASD). We investigated the effects of a pilot 30-session Makoto arena training intervention, a light and sound speed-based exergame, on response speed, EF, and motor skills in school-aged children with ASD. Strong correlations were seen between certain EF and motor scores, suggesting a relationship between the two constructs. Participants increased their average reaction speed (effect size = 1.18). Significant improvement was seen in the EF areas of working memory and metacognition and the motor area of strength and agility. Findings suggest that use of exergaming, specifically the Makoto arena, has the potential to be a valuable addition to standard intervention for children with ASD who have motor and EF impairments.

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Although not included in the diagnostic criteria for autism spectrum disorder (ASD; American Psychiatric Association [APA], 2013), executive dysfunction has consistently been observed in people diagnosed with several types of developmental disabilities, including ASD (Pennington & Ozonoff, 1996). *Executive function* (EF) refers to the higher order control processes that are necessary to guide behavior in a constantly changing environment (Jurado & Rosselli, 2007). Included in the concept of EF are planning, working memory, mental flexibility, response initiation, response inhibition, impulse control, and monitoring of action (Roberts, Robbins, & Weiskrantz, 1998; Stuss & Knight, 2002). In addition, despite the lack of identification of motor impairment in the fifth edition of the *Diagnostic and Statistical Manual of Mental Disorders* (DSM; APA, 2013) regarding ASD, the World Health Organization's (2001) *International Classification of Functioning, Disability and Health* includes motor deficit as symptom associated with ASD. Motor deficits have been reported in numerous studies of children with ASD.

Executive Function

EF allows people to initiate and organize tasks and to persevere in the face of challenges ("Executive Function," 2012). It is necessary to recognize the significance of unexpected situations and to make alternative plans quickly when unusual events arise. EF contributes to success in school and work and allows people to manage the stresses of and barriers to daily life activities. EF is also important in allowing people to inhibit inappropriate behaviors. People with poor EF often have problems with saying or doing things that are bizarre or

offensive to others. Underlying factors of common EF tasks in children have been identified as cognitive flexibility (shift), working memory, inhibition (Miyake et al., 2000), and planning (Pennington & Ozonoff, 1996).

Previous studies have not all agreed on which areas of EF are impaired in people with ASD. Findings on spatial working memory have ranged from impairments (Bennetto, Pennington, & Rogers, 1996; Sachse, Schlitt, Hainz, Ciaramidaro, & Schirman, 2013; Steele, Minshew, Luna, & Sweeney, 2007) to normal functioning (Griffith, Pennington, Wehner, & Rogers, 1999; Happé, Booth, Charlton, & Hughes, 2006; Ozonoff & Strayer 2001; Robinson, Goddard, Dritschel, Wisley, & Howlin, 2009; Russell, Jarrold, & Henry, 1996) to above-average performance (Edgin & Pennington, 2005). Steele et al. (2007) and Best, Miller, and Jones (2009) suggested that the level of task difficulty in the different measures may affect differences in outcomes in the various studies and that less demanding tasks may not be challenging enough to differentiate the ASD group from the control participants. Best et al. (2009) also stated that much of the development of EF, especially working memory, shifting, and planning, occurs after age 5, which might explain the lack of impairment found in the Griffith et al. (1999) study. Studies addressing the other EF constructs, cognitive flexibility (shift), inhibition, and planning, have found similarly dissonant results regarding their presence in children with ASD (Sachse et al., 2013).

Although EF deficits have been noted in children with ASD, studies have disagreed on whether these deficits are characteristic of ASD itself or of intellectual disability. To avoid the confounding effect of IQ effects on EF, it is important to study participants who do not have intellectual disability. Robinson et al. (2009) found that when matched with typically developing control participants on IQ and language level, participants with ASD demonstrated a specific pattern of executive impairments, exhibiting poor performance in planning, inhibition of responses, and self-monitoring. They concluded that these areas of deficit were specific to ASD rather than to intellectual disability or verbal difficulties.

Long-term effects of EF deficits have also been studied. Miller, Nevado-Montenegro, and Hinshaw (2012) found that low working memory in middle childhood in girls with attention deficit hyperactivity disorder was predictive of poor reading scores in late adolescence and young adulthood (10 yr later), and impaired global EF predicted a higher number of suspensions and expulsions from school. These findings suggest the importance of assessing and developing interventions that target EF impairments early in life to prevent long-term difficulties across a range of important functional domains.

EF has been suggested to be related to motor impairments in children. Rogers, Bennetto, McEvoy, and Pennington (1996) proposed EF impairment as the underlying mechanism contributing to imitation impairment in ASD after examining imitation and EF in 17 adolescent high-functioning participants with ASD and 15 control participants matched on age and verbal IQ. Hartman, Houwen, Scherder, and Visscher (2010) found significant relationships between motor performance and EF in a study of 61 children between ages 7 and 12 yr diagnosed with borderline intellectual disability and 36 age-matched peers with mild intellectual disability.

Motor Impairment

A range of motor impairments have been identified in studies of children with ASD that include fine and gross motor coordination, strength, agility, praxis, performance of skilled gestures, imitation, and the subtle neurological signs of overflow, dysrhythmia, motor impersistence, and muscle tone. These studies have generally converged on the notion that 80%–90% of children with ASD show some degree of motor abnormality (David et al., 2009; Dziuk, Gidley-Larson, Mahone, Denckla, & Mostofsky, 2007; Ghaziuddin & Butler, 1998; Hilton, Zhang, White, Klohr, & Constantino, 2012; Ming, Brimacombe, & Wagner, 2007).

Motor and EF deficits in children with ASD may contribute to low rates of physical activity participation by creating more of a challenge for these children to participate (Reid, O'Connor, & Lloyd, 2003). Pan and Frey (2006) found that children diagnosed with ASD are generally less active than typically developing children of the same age. In this study, 30 children with ASD were asked to wear an accelerometer to measure their amount of physical activity and to identify any patterns of activity regarding time of day or day of the week. Results provided additional information that as children with ASD grow older, their physical activity level declines.

Hilton, Crouch, and Israel (2008) similarly found from comparing children with and without ASD in three age groups (6–8, 9–10, 11–12) that older participants in the control group participated more frequently and in more activities than the younger participants, whereas children in the ASD group participated less frequently and in fewer activities. Hilton et al. (2008) also found that physical activities showed the greatest differences between the children with ASD ($n = 52$) and the typically developing control group ($n = 53$) among types of out-of-school activities in both the number of activities in which they participated and the frequency.

Todd and Reid (2006) examined the effectiveness of a reinforcement program to help improve participation in physical activity among people with autism. They found that by slightly grading the physical activities and providing motivating reinforcement, people with severe autism were able to participate in physical activity for longer durations.

Numerous recent studies have found that moderate to vigorous aerobic exercise supports improvement in aspects of EF in children (Anderson-Hanley, Tureck, & Schneiderman, 2011; Best, 2012; Budde, Voelcker-Rehage, Pietrabyk-Kendziorra, Ribeiro, & Tidow, 2008; Kamijo et al., 2011; Pesce, Crova, Cereatti, Casalla, & Bellucci, 2009). Kamijo et al. (2011) found that participation in an afterschool physical activity program significantly improved working memory in 22 preadolescent children. Anderson-Hanley et al. (2011) found significant improvement in measures of attention and working memory and significant decreases in repetitive behaviors in 12 children with ASD after participation in an exergame, *Dance Dance Revolution* (Konami, Tokyo). (*Exergames* are games that combine play and exercise; Bogost, 2005.)

We investigated the effectiveness of participating in the Makoto arena training intervention (Makoto, USA, Inc., n.d.), a motor response speed game, on EF and motor skills in school-age children with ASD. The Makoto arena training device was developed for use in performance sports, schools, and medical rehabilitation to increase reaction time, improve attention, and improve physical fitness of the people who participate (Makoto, USA, Inc., n.d.) and is classified in the category of exergames. It is a light and sound interactive game with an atmosphere similar to an arena, consisting of three towers approximately 6 ft tall, located approximately 6 ft apart from each other in a triangular formation. With 10 lights located on each of the three towers, the device works as an interactive game by illuminating lights in random order with an associated tone. Lower tones indicate that the illuminated light is located near the bottom of a tower, and higher tones indicate that the illuminated light is located near the top of a tower. Several different games and speed progressions are available with the Makoto arena and involve identifying which light has been illuminated and tapping it as quickly as possible before the allotted time runs out.

The Makoto training device measures overall accuracy and reaction time for each session and provides these scores as performance feedback (Exergame Fitness, 2011). The device also provides instant auditory reinforcement with a specific tone that sounds whenever a target light has been tapped within the allotted time.

Although a dearth of evidence has been published examining the value of using the Makoto arena training device as part of a therapeutic intervention protocol in populations with movement disorders, effects of using other exergaming devices have begun to be studied with regard to improvements in motor performance and EF. A study conducted by Sandlund, Waterworth, and Häger (2011) examined the effects of a motion-interactive PlayStation2[®] game on participation in physical activity and motor performance of children with cerebral palsy between ages 6 and 16. A 4-wk, at-home intervention yielded evidence that 8 of 10 participants increased in physical activity participation, and observations of motor improvements were noted.

Another study conducted more recently examined the effects of Wii[®] interactive games on sensorimotor function of 105 children with Down syndrome and matched controls between the ages of 7 and 12 (Wuang, Chiang, Su, & Wang, 2011). Before and after measures of the Bruininks-Oseretsky Test of Motor Proficiency, Second Edition (BOT-2), the Developmental Test of Visual Motor Integration, and the Test of Sensory Integration Function were used in both groups with a 24-wk intervention, and Wuang et al. (2011) found that Wii interactive gaming was effective in improving motor proficiency, visual integrative abilities, and sensory integrative functions in the children with Down syndrome. They also found that the children with Down syndrome experienced greater improvements than the typically developing control children between pre- and postassessment with the BOT-2.

The existing exergaming studies have provided evidence to suggest that these alternative forms of intervention may help to improve participation, reaction time, EF, and motor performance in children with various conditions. With these improvements, children with ASD have the potential for enhanced quality of life because increased participation, reaction time, EF, and motor performance will lead to more possibilities and allow for a more functional future (Bölte, Golan, Goodwin, & Zwaigenbaum, 2010).

In the current study, we investigated the effectiveness of a Makoto arena training intervention on response speed, EF, and motor performance in school-age children with ASD. The research questions asked were as follows:

1. Does response speed improve after participation in the Makoto arena intervention?
2. Does EF improve after participation in the Makoto arena intervention?
3. Does motor performance improve after participation in the Makoto arena intervention?

We hypothesized that children with ASD would improve in response speed, EF, and motor performance after participating in the Makoto arena intervention.

Method

Research Design

We used a single-group pretest–posttest research design. Ethical approval for this study was obtained from the Institutional Review Board and Human Research Protection Office at Washington University School of Medicine.

Participants

Participants were recruited from among students enrolled at a private school (the Clayton Child Center) in St. Louis, Missouri, and from other families in the metropolitan area through parent networks. A diagnosis of ASD, a full-scale IQ score of ≥ 70 , and a willingness to participate in the Makoto arena intervention approximately 3 times per week were required for inclusion in this study. Students with lower IQs were excluded to avoid the potential for confusion between impaired intelligence and impaired EF. IQ was determined by administration of the Wechsler Abbreviated Scale of Intelligence (Wechsler, 1999). IQ scores were as follows: full scale, 72–136 (mean = 105); verbal, 85–151 (mean = 110); and performance, 62–143 (mean = 99).

ASD diagnosis was determined by an experienced clinician according to the criteria of the fourth edition, text revision, of the *DSM* (American Psychiatric Association, 2000). Exclusion criteria were inability to follow directions, severe behavioral difficulties, or limitations in vision and hearing that might compromise the child's awareness of the visual and auditory cues provided in the Makoto arena. In addition, children without the ability or willingness to commit to participation in the Makoto arena intervention a minimum of 3 times per week were excluded from the study.

Measures

Children who were considered eligible for inclusion in the study were evaluated before and after intervention with the Behavior Rating Inventory of Executive Function (BRIEF) and the BOT–2. Average reaction speed was recorded for each participant for each Makoto arena intervention session.

The BRIEF (Gioia, Isquith, Guy, & Kenworthy, 2000) is an 86-item standardized parent-report questionnaire that assesses the behavioral manifestations of EF abilities in children. It capitalizes on observations of children in their naturalistic settings to quantify their EF impairments

during participation in regular life activities. Higher scores on the BRIEF indicate greater EF problems, with scores >65 reflecting executive impairments. Clinical scales assessed were Inhibit (resisting or not acting on impulse), Shift (moving freely from one situation to another), Emotional Control (ability to modulate emotional responses), Initiate (initiating a task or generating ideas), Working Memory (ability to hold information in mind to complete a task), Plan/Organize (ability to manage current and future-oriented task demands), Organization of Materials (orderliness of work, play, and storage spaces), and Monitor (work-checking habits). The clinical scales were combined to form two indexes, 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. Strong internal consistency reliability (.82–.98) and test–retest reliability (.72–.83) and moderate interrater reliability (overall mean $r = .32$) have been established, and content and construct validity for this assessment are good (Gioia et al., 2000). For content validity, questions were examined and scored by an expert panel of 12 pediatric neuropsychologists and the authors. For construct validity, correlations (mostly in the upper .30s–.70s) between categorical scores and Inattention and Hyperactivity–Impulsivity scores from the ADHD Rating Scale–IV (DuPaul, Power, Anastopoulos, & Reid, 1998) were examined.

The BOT–2 (Bruininks & Bruininks, 2005) is a standardized measure of motor proficiency that assesses fine manual control (fine motor precision and integration), manual coordination (manual dexterity and upper limb coordination), body coordination (bilateral coordination and balance), and strength and agility (running speed and agility and strength). It generates gender- and age-specific standard subscale scores and a total motor composite score and has been normed for children and youth between ages 4 and 21. Strong internal subtest consistency reliability (high .70s–low .80s), internal composite consistency reliability (mostly between the high .80s and low .90s), test–retest reliability (.69–low .80s), and interrater reliability (.92–.99) have been established for the BOT–2, and it is available for use with the age range of the participants in this study (Bruininks & Bruininks, 2005).

To establish good content validity, a product survey and three focus groups began the process of revising items from the original assessment. After that, new items went through a pilot study, and all items went through national tryout and standardization. Correlations with the Peabody Developmental Motor Scale, Second Edition (Folio & Fewell, 2000) comparing scores for 4- and 5-yr-

olds were strong (.64–.75) for all categorical scores except for a moderately strong association (.51) for the fine motor score, showing good construct validity.

For this study, all BOT–2 assessments were videotaped, and all seven examiners achieved interrater item-level reliability of >90% before scoring the assessments. Higher scores on the BOT–2 items indicate higher motor proficiency.

Intervention

Participants completed 2-min sessions of Makoto arena intervention a minimum of 3 times per week until 30 intervention sessions were completed, with each participant attempting to strike the target approximately 1,800 times. Participants were instructed to strike lighted targets with a ball as quickly as they could. Each participant began the intervention at the slowest speed level (Level 1) and, when mastery was achieved (>95% strikes in the time allowed), were increased to the next speed level at their next session. With each increase in speed level, the amount of time allowed to react and strike the target was less, thus encouraging increased reaction time by the participants. The Makoto arena has the option of using preset speed levels, but we set the speed level between those for fitness and rehabilitation in an attempt to balance the opportunity for challenge and success for the participants. The 11 levels were set at 3 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

All assessments and interventions were administered by graduate students or the principal investigator (Claudia List Hilton), all trained and reliable in the use of the assessments and the Makoto arena intervention. Assessments were administered in quiet rooms at the Clayton Child Center or at the Washington University School of Medicine in St. Louis, Missouri. The intervention was administered in a small room with limited distractions at the Clayton Child Center and was started within 1 mo of pretesting for each child; posttesting was completed within 1 mo of completion of the intervention.

Statistical Analyses

Data were analyzed using IBM SPSS Statistics 20 (IBM Corporation, Armonk, NY). Because of the small sample size, we used nonparametric measures to analyze the BRIEF and BOT–2 data. We compared mean t scores with test norms and examined Spearman ρ correlation coefficients between EF and motor subscale t scores for pretests. Mean t scores for pretest and posttest were compared and analyzed

by means of paired Wilcoxon signed rank tests to detect significant effects related to intervention. We also analyzed reaction speed means between Sessions 6 and 30 by means of paired Wilcoxon signed rank test to determine significant changes. Additionally, we calculated standardized effect sizes (Cohen's d ; [Cohen, 1988](#)) for the pretest–posttest scores. The p value for significance was set at $p < .05$.

Results

Recruitment efforts produced 8 participants who enrolled in the study. One child was discontinued because of unwillingness to follow the protocol directions (the child would throw the ball at the target instead of hitting the target with the ball), leaving 7 participants (5 boys, 2 girls) who completed the protocol. Participants had an ASD diagnosis and were between 6.41 and 13.9 yr old (mean = 9.86) at the beginning of intervention.

Mean scores for BRIEF pretesting indicated that the Inhibit, Shift, Working Memory, and Monitor scales; the behavioral regulation and metacognition indexes; and the global executive composite were all >1 standard deviation above the norm, indicating greater impairment. Means of BOT–2 scores also indicated impairment, but were <1 standard deviation below the norm.

We found several significant strong negative correlations between pretest motor and EF t scores. Total motor composite was significantly correlated with the EF metacognition index ($r = -.805$, $p = .029$). The correlation between total motor composite and the other EF behavioral regulation index was high but not significant ($r = -.580$), as was the correlation with the global executive composite ($r = -.718$).

The children each had five practice trials to allow them to understand the task that were not included in the analyses. Mean speeds from the sixth and last Makoto arena intervention sessions were compared. Participants' reaction speed increased, with a very large effect size of 1.8 ([Cohen, 1988](#)). See Figure 1 for details. None of the children in this group were able to advance past Level 9 speed.

We compared the means of pretest and posttest t scores for the BRIEF and BOT–2. Improvement was observed in all areas of the BRIEF except the Inhibit scale. Significant improvement was observed in the BRIEF's Working Memory scale, which showed a large effect size ($d = -1.01$), and the metacognition index, which indicates general improvement in the ability to initiate, plan, organize, and sustain future-oriented problem solving in working memory. Items showing the greatest improvement in working memory were trouble with multistep chores, forgetting what he or she is doing, and forgetting what to get when he or she is sent to get something. Motor t scores showed

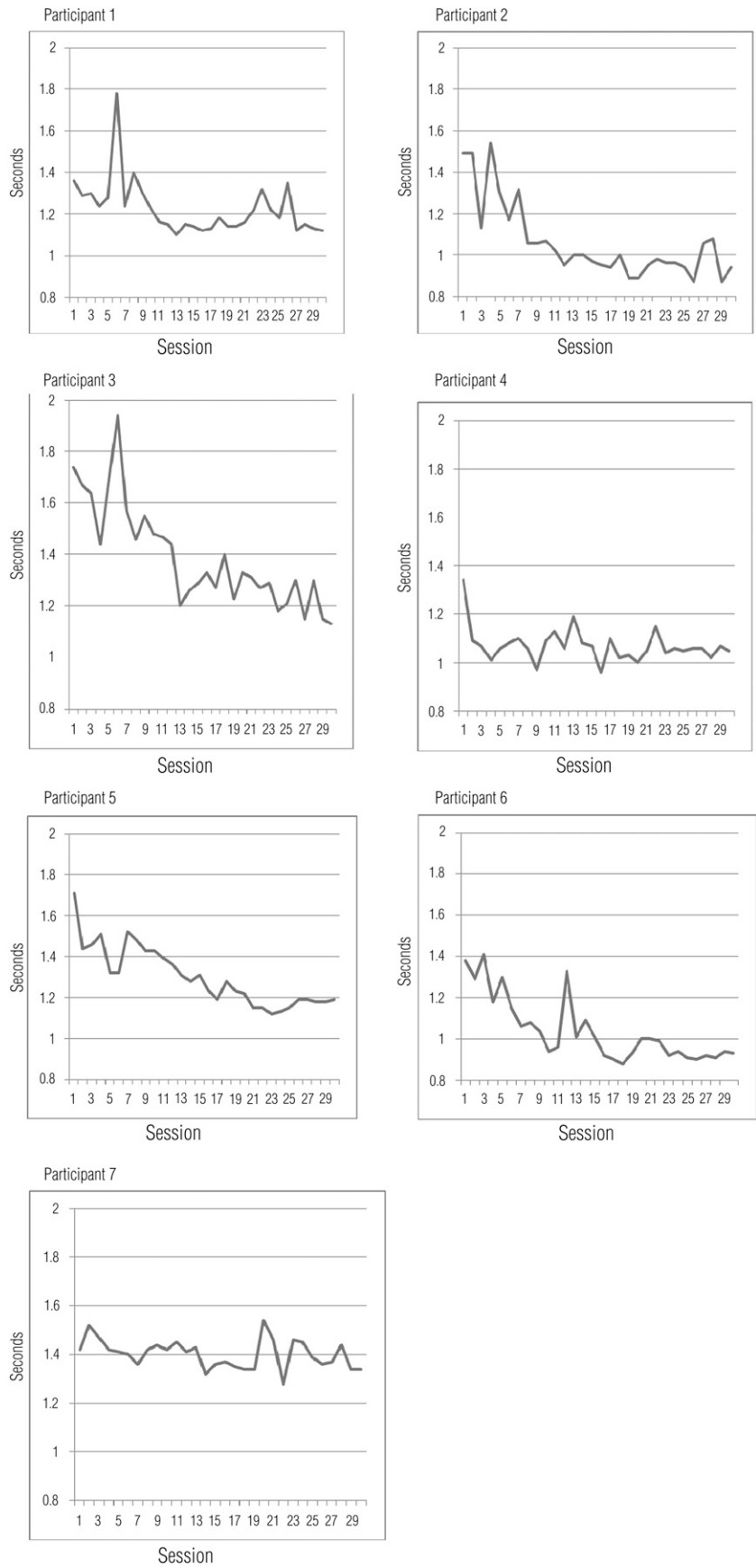


Figure 1. Average Makoto speed at each session.

significant improvement only in the motor area of strength and agility. The most improved item was running speed. Some improvement was also seen in manual coordination and total motor composite. See Table 1 for details.

Discussion

Finding impairment at pretest on the Inhibit, Shift, Working Memory, and Monitor scales; behavioral regulation and metacognition indexes; and the global executive composite of >1 standard deviation supports previous findings from several previous studies of EF in children with ASD indicating impairment in these areas. Means of <1 standard deviation for impairment in motor skills in this group of children indicates a less impaired motor baseline than in most children with ASD. Findings of strong negative correlations in pretesting between certain EF and motor subscales indicate a relationship between certain aspects of the two constructs for this cohort, which supports previous findings (Hartman et al., 2010; Rogers et al., 1996). They also suggest the possibility that interventions directed toward improvement in one could also have an impact on the other. The generalizability for this finding could be improved by replicating the study with a larger cohort.

We observed overall patterns of improvement in reaction speed, EF, and motor performance after participation in the Makoto arena intervention. Small improvements in EF and motor areas could suggest that, given a larger sample size or possibly a longer duration of intervention, children

with and without ASD may show significant improvement in these areas as well.

Having to remember each aspect of how to respond to the sounds and lights to be successful in the Makoto arena may possibly generalize to having better focus and working memory for other tasks in the children's daily lives. The almost moderate effect size of improvement in strength and agility for the children with ASD may be a result of the need for them to repeatedly move quickly and efficiently between the towers and the targets, coordinating their upper- and lower-extremity movements to hit the targets in the time allowed. It is possible that a larger effect would be seen and in other areas of motor proficiency with a longer duration of intervention or if ASD-affected participants had demonstrated a greater degree of motor impairment at pretest.

Given the improvements observed in reaction speed, motor performance, and EF through comparison of pre- and posttest scores, the Makoto arena training device may serve as a valuable addition to other types of therapy for children with ASD who have EF and motor impairments. This device appeared motivating for the children and was both quick and easy to use, and improvements seen in performance of the Makoto arena intervention translated to the activities and everyday tasks involved in both assessments. The Makoto arena intervention may be useful as a warm-up intervention to support traditional therapy with the potential for greater improvement in motor performance and EF important for everyday activity participation.

Table 1. Pre- and Postintervention Scores (N = 7)

Test	Preintervention, <i>M</i> (<i>SD</i>)	Postintervention, <i>M</i> (<i>SD</i>)	<i>p</i>	<i>d</i>
Makoto Average Speed, 6th and 30th trial, s	1.40 (0.33)	1.10 (0.14)	.018*	1.18
BRIEF, <i>t</i> score (<i>M</i> = 50, <i>SD</i> = 10)				
Inhibit	62.00 (11.17)	63.86 (14.37)	<i>ns</i>	0.14
Shift	63.86 (10.22)	60.14 (10.27)	<i>ns</i>	-0.36
Emotional control	59.57 (7.91)	58.71 (10.92)	<i>ns</i>	-0.11
Behavioral regulation index	63.14 (7.99)	62.71 (11.40)	<i>ns</i>	-0.04
Working memory	64.57 (9.25)	55.14 (10.79)	.027*	-1.01
Plan-organize	56.43 (8.77)	53.43 (9.16)	<i>ns</i>	-0.33
Organization of materials	51.86 (12.86)	48.29 (13.76)	<i>ns</i>	0.28
Monitor	61.86 (7.82)	58.86 (12.97)	<i>ns</i>	-0.38
Metacognition index	60.43 (9.74)	54.86 (11.38)	.027*	-0.53
Global executive composite	61.43 (8.96)	58.29 (10.56)	<i>ns</i>	-0.32
BOT-2, standard scores (<i>M</i> = 50, <i>SD</i> = 10)				
Fine manual control	47.71 (13.38)	46.14 (12.48)	<i>ns</i>	-0.12
Manual coordination	42.29 (10.08)	44.57 (4.65)	<i>ns</i>	0.31
Body coordination	49.00 (10.95)	48.29 (8.38)	<i>ns</i>	0.00
Strength and agility	42.71 (9.50)	46.71 (8.06)	.017*	0.46
Total motor composite	43.71 (13.25)	44.57 (8.68)	<i>ns</i>	0.08

Note. BOT-2 = Bruininks-Oseretsky Test of Motor Proficiency-Second Edition; BRIEF = Behavior Rating Inventory of Executive Function; *M* = mean; *ns* = nonsignificant; *SD* = standard deviation.

**p* < .05.

Limitations and Future Research

The small sample size of this pilot study and the lack of a control group are limitations to its generalizability. Findings from this pilot study suggest that further examination of the value of the Makoto arena intervention is warranted. Completion of a randomized controlled trial with a larger cohort and inclusion of an observation-based measure of EF and maintenance of improvements would add to the scientific rigor of the findings and strengthen their generalizability. Additional research should be conducted to replicate and extend these findings, to clarify exergaming components that may influence cognitive and motor outcomes, and to examine the long-term and applied utility of exergaming for ASD.

Implications for Occupational Therapy Practice

The major findings of this study and their implications for practice are as follows:

- This pilot study provides initial evidence suggesting that exergaming, specifically use of the Makoto arena, may be useful for improving EF and motor skills in children on the autism spectrum. Identification of effective, interesting, and motivating interventions is important to provide the optimal impact through therapy for children with ASD.
- We found significant correlations between certain EF and motor scores, suggesting 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 valuable steps toward best practice. ▲

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