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# MULTILATERAL TRAINING USING PHYSICAL ACTIVITY AND SOCIAL GAMES IMPROVES MOTOR SKILLS AND EXECUTIVE FUNCTION IN CHILDREN WITH AUTISM SPECTRUM DISORDER

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**Abstract:**
While impairments in gross and fine motor skills and executive function are evident from an early age in individuals with autism spectrum disorder (ASD), few studies have explored combined physical activity training and social games as a means of improving these proficiencies in children with ASD. We examined the effects of a 12-week Multilateral Training intervention in 24 children with ASD (*M* age =9.33, *SD* = 0.92 years). Participants were matched into pairs, based on age, gender, and autism symptom severity, and we randomly allocated each pair into either an intervention ($n$ = 12) or waitlist control ($n$ = 12) group. Participants in the intervention group performed two 70-minutes sessions per week consisting of a 5-minute warm-up, 40 minutes of motor skills training related to EF (over four progressive levels), 20 minutes of social games, and a final 5-minute cool-down. At baseline and again after the intervention, we administered the Bruininks-Oseretsky Test of Motor Proficiency, 2nd edition (BOT-2), and the Behavior Rating Inventory of Executive Function (BRIEF) to assess all participants' gross and fine motor skills and EF, respectively. Results showed that the intervention group significantly improved motor skill proficiency (i.e., BOT-2 total motor composite and three motor-area composites) and EF (i.e., BRIEF global EF composite and three EF indices) ($p < 0.05$; $d > 0.84$). These findings support the efficacy of Multilateral Training to assist children with ASD with both physical and cognitive/behavioral symptoms.

**Keywords:** working memory; cognitive flexibility; inhibitory control; motor performance; physical activity

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## 1. Introduction

Autism spectrum disorder (ASD) is a high-prevalence neurodevelopmental condition which often results in significant impairment of social interactions and restricted, repetitive patterns of behavior or interests, such as repeated motor movements or speech, rigidity in routines or patterns, and atypically intense preoccupations with a limited range of interests (American Psychiatric Association (APA), 2013). The International Classification of Functioning, Disability, and Health lists motor skill deficits as an ASD-associated symptom (World Health Organization, 2001); however, in the Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition (DSM-V), there are no specific identifiers for the impairment of motor capacity related to the ASD (APA, 2013). Between 50 and 100% of individuals with ASD have motor difficulties that include incoordination during gross and fine motor activities, poor balance skills, and clumsy gait patterns (Bhat, Landa, & Galloway, 2011; Fournier, Hass, Naik, Lodha, & Cauraugh, 2010; Provost, Heimerl, & Lopez, 2007). Yet, the relationship between motor skills and ASD remains an overlooked research topic in the ASD pediatric literature.

Motor impairments in children with ASD have implications for their future social, cognitive, and communication development (Leary & Hill, 1996). Impairments in basic gross motor skills such as running, jumping, and hopping can limit children's play with peers and restrict their opportunities to build social connections (Bhat et al., 2011; Leary & Hill, 1996). Moreover, poor manual motor skills such as pointing, and reaching have implications for nonverbal modes of communication such as the use of gestures and engaging in joint attention bids (Gernsbacher, Stevenson, Khandakar, & Goldsmith, 2008). Impairments in gross and fine motor performance are evident from an early age in individuals with ASD (Isenhower et al., 2012; Stevenson, Lindley, & Murlo, 2017). In terms of gross motor performance, children have significant impairments in postural control (Freitag, Kleser, Schneider, & von Gontard, 2007; Minshew, Sung, Jones, & Furman, 2004), gait patterns (Rinehart et al., 2006), and bilateral coordination skills (Isenhower et al., 2012). Likewise, children with ASD have impaired fine motor skills involving object control and manual dexterity (Berkeley, Zittel, Pitney, & Nichols, 2001; Sacrey, Germani, Bryson, & Zwaigenbaum, 2014), visuomotor integration (Provost et al., 2007), and hand-writing (Fuentes, Mostofsky, & Bastian, 2009; Kushki, Chau, & Anagnostou, 2011). A meta-analysis based on 51 studies comparing children with ASD and typically developing (TD) children demonstrated a large effect size ($d \geq 0.80$) for motor issues in gait, postural control, motor coordination, upper limb control, and motor planning in ASD (Fournier et al., 2010). Also, Staples & Reid (2010) demonstrated that children with ASD performed movement skills at a level equivalent to typically developing children who were half their chronological age (i.e., 10-year-old ASD children performed motor skills equivalent to 5-year-old typically developing children). The significant motor delays experienced by school-age children with ASD indicate a need to create motor skill interventions to minimize motor delays and promote optimal overall development. Indeed, previous studies have shown that physical activity interventions can be effective for improving motor skills in children with ASD (aged 4–18 years) (Bass, Duchowny, & Llabre, 2009; Bremer, Balogh, & Lloyd, 2015; MacDonald et al., 2012; Pan, 2010; Wuang, Wang, Huang, & Su, 2010).

In addition to impaired motor skills, executive dysfunction has been frequently observed among people diagnosed with ASD (Diamond, 2013; Hill, 2004). Executive functioning (EF) (Diamond, 2013; Hill, 2004) constitutes a varied group of inter-related cognitive processes that drive goal-directed behaviors. While definitions vary among theorists, as measured by the term EF typically includes three core processes of behavioral inhibition (i.e., the control and override of behavioral urges such as maintaining social politeness), working memory (i.e., holding information in mind while mentally manipulating it, such as doing mental arithmetic), and cognitive flexibility (i.e., adjusting to changed demands such as considering ideas from a new perspective) (Diamond & Lee, 2011). Other aspects of EF include verbal and nonverbal fluency (i.e., generating ideas and concepts such as listing words that start with a certain letter), planning/problem solving, and reasoning (Diamond & Lee, 2011). All aspects of EF continue to develop and strengthen throughout early childhood and into middle childhood (9-11 years). Compared to their typically developing peers, children with ASD demonstrate poorer EF (Stevenson et al., 2017; Zelazo & Müller, 2010), particularly with respect to poorer planning abilities and cognitive flexibility (Hill, 2004). ASD symptoms such as restricted and repetitive behavior patterns (e.g., hand flapping, finger flicking, and self-injury) have been seen as highly associated with EF impairment (Ozonoff & Schetter 2007). Although there is some evidence to support the beneficial effects of physical activity on EF, with some studies showing large effects to these interventions for children (Bahrami, Movahedi, Marandi, & Abedi, 2012; Chan, Sze, Siu, Lau, & Cheung, 2013; Hilton et al., 2014; Toscano, Carvalho, & Ferreira, 2018), still few studies have explored physical activity as a means to improve EFs of children with ASD.

Therefore, we sought to test Multilateral Training in this population, as it is a specific program in physical activity and social games that targets multiple components of fitness and merges motor skill training (i.e. locomotor and object control skills) with EF training. We hypothesized that a 12-week Multilateral Training intervention would improve both motor skill proficiency and EF in children with ASD.

## 2. Material and Methods

### 2.1 Participants

For participation in this study, we randomly recruited 24 children with ASD (20 males and 4 females) ranging in age from 8-11 years (*M* age= 9.33, *SD* =0.92 years) from students attending a local autism treatment center. This age range was selected because of the normative emergence of beginning skills in EF at around age 8 -9 years and because we sought to avoid confounding highly variable individualistic effects of the onset of puberty after around age 11-12 years. We conducted statistical power calculations to determine the participant sample size required to detect changes in the dependent measures resulting from the intervention. On the basis of an *a priori* power analysis (Faul, Erdfelder, Lang, & Buchner, 2007) with an assumed type I error of 0.05 and a type II error rate of 0.20 (95% statistical power), we found that 24 participants would be sufficient to observe medium 'Time x Group' interaction effects. Parents of all participants signed informed written consents for their children's participation in this study.

All children received a parent-reported clinical diagnosis of ASD based on ADOS-2 (Autism Diagnostic Observation Schedule) scores, which is a standardized, semi-structured, observational assessment of ASD (Lord et al., 2012). Consistent with the 4:1 gender ratio of ASD incidence that is commonly reported in the ASD literature (Jacquemont et al., 2014), most participants in our sample were boys (83.3%, $n$ = 20). Average ADOS-2 scores indicated that autism symptom severity in the overall sample was moderate to high ($M$ = 7.13, $SD$ = 1.42). Furthermore, other participant inclusion criteria were the ability to follow directions and perform requested motor skill proficiency and EF measures and no history of reading disabilities, according to parents. A physician screened all participants and found them physically able to participate to the intervention program.

After pre-intervention assessments, participants were matched into pairs based on age, gender, and autism severity, and randomly allocated members of each pair into either the intervention group ($n$ = 12; $M$ age = 9.25, $SD$ = 0.97 years; 10 males and 2 females; $M$ ADOS-2 score = 7.08 , $SD$ = 1.78) or the waitlist control group ($n$ = 12; $M$ age = 9.42, $SD$ = 0.90 years; 10 males and 2 females; $M$ ADOS-2 score = 7.17, $SD$ = 1.03). The researchers were blinded to this randomization of intervention and control group allocations. We selected participants of both groups from the same autism institute to ensure that they received the same treatment strategies. Families of all participants belonged to the middle-class socioeconomic status. We recruited children with ASD and their families in the period from January to February 2019. No children dropped out of the study.

## 2.2 Procedures

All procedures were in accordance with the ethical standards of the responsible institutional committee on human experimentation and with the Helsinki Declaration. The study was conducted from March to May 2019, during which intervention group participants received 12 weeks of the Multilateral Training intervention. As noted above, before intervention (baseline) and post-intervention (week 12), we assessed all participants' motor skills proficiency and EF.

Since the intervention was complex and the techniques were difficult over 12 weeks, it was necessary to use some strategies to motivate these children with ASD to participate in the intervention. Therefore, within the Multilateral Training intervention group, we used several attentional directing strategies including verbal exhortation, verbal augmented feedback, visual demonstration/modeling, attentional cueing, and visual cues including pictures, line, and spots drawings on the floor which gradually were disregarded (Ayers & Sariscsany, 2010) to facilitate learning procedure in children with ASD. Additionally, we also used some teaching strategies, including fractionization, segmentation and simplification, verbal instruction and verbal cues (as directing attention or prompting actions), modeling, and physical/manual guidance (Ayers & Sariscsany, 2010) to instruct exercises to the participants in the intervention group.

### 2.3 Measures

All measurements were conducted in the gym with a parent present. We assessed changes in gross and fine motor performance using the Bruininks-Oseretsky Test of Motor Proficiency, 2nd edition (BOT-2; Bruininks & Bruininks, 2005). An assessor who was blinded to the grouping of the children conducted the BOT-2 assessment at the designated pre-intervention and post-intervention sessions. Also, before the initial assessment, we required the participants' parents to precisely observe the participants at home for seven days in order that they might be interviewed for an assessment of the children's executive functioning with the Behavior Rating Inventory of Executive Function (BRIEF; Gioia, Isquith, Guy, & Kenworthy, 2000).

#### 2.3.1 Standardized Test of Motor Performance

The BOT-2 (Bruininks & Bruininks, 2005) measures an array of motor skills in people aged 4–21 years. It uses a composite structure organized around the muscle groups and limbs involved in movements. The following four motor-area composites exist, and each composite comprises two subscales, each composed of five to nine items (53 total items): (1) fine manual control (fine motor precision and integration), (2) manual coordination (manual dexterity and upper-limb coordination), (3) body coordination (bilateral coordination and balance), and (4) strength and agility (running speed and agility and strength). Each composite generates gender- and age-specific standard subscale scores; the four composite scores were combined to obtain a total motor composite score. The BOT-2 takes 15 – 25 minutes to complete. Higher scores indicate better motor performance.

The BOT-2 was chosen for this study because it is one of the most widely used performance-based measures (Bhat et al., 2011) and provides norms for the age group of children included in this study (Bruininks & Bruininks, 2005). Its validity and reliability were demonstrated in evaluation of children with developmental coordination disorders, mild intellectual disabilities, and high-functioning autism or Asperger disorder (Bruininks & Bruininks, 2005; Wuang & Su, 2009). Bruininks and Bruininks (2005) established strong internal subtest consistency reliability ($r$ = 0.70–0.80), internal composite consistency reliability ($r$ = 0.80–0.90), test-retest reliability ($r$ = 0.69–0.80), and interrater reliability ($r$ = 0.92–0.99) for the BOT-2 manual. In this study, the internal consistency reliability of the subtests and composites was high, determined by a Cronbach's alpha between 0.83 and 0.88.

#### 2.3.2 Behavior Rating Inventory of Executive Function (BRIEF)

The BRIEF is an 86-item parent and/or teacher rating scale designed to assess executive functioning and self-regulation in children and adolescents ages 5 – 18 years (Gioia et al., 2000). The BRIEF takes 10 – 15 minutes to complete. Parents were given the BRIEF at pre- and post-test and reported on children's functioning on three indexes of EF, with each index consisting of multiple clinical scales: Behavior Regulation Index (BRI; scales: inhibit, self-monitor), Emotion Regulation Index (ERI; scales: shift, emotional control), and Cognitive Regulation Index (CRI; scales: initiate, working memory, plan/organize, task-monitor, organization of materials). The three indices were combined according to the scoring instructions to yield a Global Executive Composite (GEC) score. Higher scores indicate poorer executive functioning on all the scales, indexes and composite scores. The BRIEF has high internal consistency and test-retest reliability (Gioia et al., 2000). In this study, the internal consistency level was high, determined by a Cronbach's alpha of 0.87.

### 2.4 Intervention

The Multilateral Training program that targets multiple components of fitness and was designed specifically for improving fitness and motor skill competency in typically developing children (Greco, Cataldi, & Fischetti, 2019). This program requires minimal equipment and has the potential to align with physical education and sports goals at school. However, the present intervention was specifically adapted to address the challenges in motor skills proficiency and executive functioning faced by children with ASD by teaching multiple tools, incrementally making them more complex and challenging multiple components of EF while flexibly applying and generalizing the learned skills across a variety of contexts.

The intervention group performed 12 weeks of Multilateral Training for 24 sessions (two 70-minute sessions per week) in a school gym. Each intervention session was conducted by the primary investigator, assisted by graduate research assistants; the instructor-to-child ratio ranged from 1:2 to 1:1, depending on attendance. All research assistants, graduates in physical education, special education, or adapted physical education, had experience with children with ASD. The duration and intensity of the intervention were modeled on training protocols from previous studies (Pan et al., 2017; Tsai, Wang, & Tseng, 2012) to increase the likelihood of the children being able to complete the full intervention. Each intervention session consisted of four activities: 5-minute warm-up, 40-minute motor skills training related to EF, 20-minutes social games, and 5-minute cool-down. The second activity was intended to be the main session of the intervention involving specific components that are designed to increase the child's motor skills and EF. This activity consisted of four progressive motor skill training levels and required the active use of the three core EFs consisting of the manipulation of the task (e.g. the colors, direction, interval, and speed of the balls) and the social environment (e.g. peers and instructors). The program used children's behavior inhibition to attend to the instructor's demonstrations and practiced their working memory to remember the different rules and move different parts of their bodies accordingly. Children also learned cognitive flexibility when they were asked to mentally manipulate what was previously learned and to accommodate to new information as it was presented. Verbal exchanges between an instructor and the children with ASD were emotionally neutral (no up and down intonations), free of jargon, and free of sarcasm or judgment to minimize frustration and distraction during conversations, and to potentially increase learning ability (Zhang & Griffin, 2007). The activities, and the training content and goals of the intervention are listed in Table 1.

**Table 1**: Twelve-week Multilateral Training program followed by the intervention group (2 sessions·wk$^{-1}$)

| Duration (time) | Activity | Training contents | Goals |
|---|---|---|---|
| 5 min | Warm-up | Week 1-12<br>• Warm-up activities: exercises including jogging, jumping, etc.<br>• Stretching activities: Achilles' tendon/calf stretches, skier's stretches, quadriceps stretches, back stretches, etc. | Warm-up and stretching |
| 40 min | Motor skills + executive function training (i.e., inhibitory control and attention)<br><br>*Overall goals*<br>• Each child would prepare to respond by processing actual visual information, planning his response, and then programming the appropriate action or inhibition response<br>• 1-to-2 to 1-to-1 instructor-to-child ratio | Week 1-3<br>Exercises with small and big pieces of equipment, somersaults, ball control (balls of different sizes and weight), circuits and courses. | Basic motor and postural scheme<br>Reinforcement of the spatial-temporal organization<br>Opto-manual coordination<br>Individually learn specific skills related to executive function |
| | | Week 4-6<br>Exercises with small and big pieces of equipment, varied circuits, blindfolded courses. | Reinforcement of the running scheme<br>Reinforcement of the static-dynamic balance<br>Reinforcement of the throwing-grasping scheme<br>Introduction to the sense of direction<br>Individually learn specific skills related to executive function. |
| | | Week 7-9<br>Exercises with small pieces of equipment and with balance beams, different types of jumping, somersaults, pulling | Reinforcement of the balance control in precarious situations<br>Improvement of joint mobility |

| | | | |
|---|---|---|---|
| | | and pushing, varied circuits, relays. | Improvement of strength<br>Integration between motor and postural schemes<br>Individually learn specific skills related to executive function. |
| | | Week 10-12<br>Exercises with small pieces of equipment, somersaults, spins, rotations on the body axis, varied circuits, relaxation, and respiratory control exercises. | Reinforcement of the sense of direction<br>Integration between different motor schemes<br>Reinforcement of the respiration control<br>Development of motor planning<br>Individually learn specific skills related to executive function. |
| 20 min | Social games | Week 1-12<br>• Cooperative games/activities (shuttle-run, red light-green light to practice starting and stopping one's body, dodgeball, etc.)<br>• Fun and challenging activities (jumping rope, line jumps, running, wind sprints, etc.) | Social interaction and sportsmanship development<br>Integrating previously learned skills<br>Fitness training |
| 5 min | Coll-down | Week 1-12<br>Slow walk/jog/stretch, comments | Review and reward |

**2.5 Statistical Analyses**

We carried out statistical analyses for this study using SAS JMP® Statistics (Version <14.3>, SAS Institute Inc., Cary, NC, USA, 2018). We presented data as group mean values and standard deviations, and we checked for assumptions of normality (i.e. Shapiro-Wilk test) and homogeneity of variances (i.e. Levene test) in the data distribution. We used an independent sample *t*-test to evaluate group differences at baseline, and we conducted a two-way ANOVA (group (intervention/control) × time (pre/post-intervention)), with repeated measures on the time dimension, to examine the effect of the Multilateral Training on all dependent variables. When 'Group x Time' interactions reached statistical significance, we conducted group-specific post hoc tests (i.e., paired *t*-tests) to identify the significant comparisons.

We calculated partial eta squared ($\eta^2_p$) to estimate the magnitude of the difference within each group, and we interpreted findings following these criteria: small ($\eta^2_p < 0.06$), medium ($0.06 \leq \eta^2_p < 0.14$), large ($\eta^2_p \geq 0.14$). We used Cohen's $d$ to determine effect sizes for the pairwise comparisons and interpreted these as small ($0.20 \leq d < 0.50$), moderate ($0.50 \leq d < 0.79$) and large ($d \geq 0.80$) (Cohen, 1992). We set statistical significance at $p < 0.05$.

## 3. Results

Participant adherence to the intervention was 91.0 % (21.85 actual sessions/24 intended sessions), and all parents of children receiving the intervention reported wanting to continue the Multilateral Training program after the intervention and solicited those who were part of the waitlist control group to start the program. We found no significant baseline differences between groups in age or autism symptom severity on the ADOS-2. Pre- and post-intervention results for all dependent measures are presented in Table 2.

**Table 2**: Mean Scores (standard deviations) and Changes in Motor Proficiency and Executive Function in ASD children after 12-weeks of Multilateral Training

| | **Intervention group (n = 12)** | | | **Control group (n = 12)** | | |
|---|---|---|---|---|---|---|
| | **Pre-test** | **Post-test** | **Δ** | **Pre-test** | **Post-test** | **Δ** |
| **Bruininks–Oseretsky Test of Motor Proficiency (BOT-2)** | | | | | | |
| Fine Manual Control | 47.5 (3.5) | 48.0 (3.0) | 0.5 (5.5) | 46.3 (3.9) | 46.5 (3.6) | 0.2 (0.9) |
| Manual Coordination | 45.8 (2.6) | 52.2 (2.5)†* | 6.4 (3.3) | 46.2 (3.4) | 46.0 (3.3) | -0.2 (0.6) |
| Body Coordination | 48.9 (2.0) | 55.5 (2.2)†* | 6.6 (2.5) | 50.1 (2.8) | 49.9 (3.4) | -0.2 (1.1) |
| Strength and Agility | 53.7 (2.3) | 62.1 (2.0)†* | 8.4 (2.9) | 54.3 (3.7) | 54.7 (4.0) | 0.3 (1.6) |
| Total Motor Composite | 49.0 (0.9) | 54.4 (1.3)†* | 5.5 (1.8) | 49.2 (1.5) | 49.3 (1.6) | 0.1 (0.5) |
| **Executive Function: Behavior Rating Inventory (BRIEF)** | | | | | | |
| Behavior Regulation | 72.3 (8.2) | 68.9 (7.1)†* | -3.4 (2.9) | 71.8 (8.9) | 72.3 (8.7) | 0.5 (1.0) |
| Emotion Regulation | 70.3 (7.6) | 67.3 (6.8)†* | -3.1 (1.1) | 72.8 (9.9) | 73.6 (9.5) | 0.8 (1.4) |
| Cognitive Regulation | 69.9 (6.8) | 67.7 (7.5)†* | -2.3 (1.2) | 70.4 (10.0) | 70.3 (10.8) | -0.2 (2.6) |
| Global Executive Functioning Composite | 75.1 (6.7) | 72.2 (7.9)†* | -2.9 (3.4) | 74.8 (7.4) | 75.3 (7.0) | 0.4 (1.0) |

**Notes:** Δ: pre- to post-training changes; †Significant 'Group x Time' interaction: significant effect of the intervention ($p < 0.05$). *Significantly different from pre-test ($p < 0.05$).

### a. BOT-2

A two-factor repeated measures ANOVA found significant 'Time x Group' interaction effects for the Total Motor Composite ($F_{1,22} = 107.19$, $p < 0.001$, $\eta^2_p = 0.83$) and three motor-area composites: Manual Coordination ($F_{1,22} = 46.67$, $p < 0.001$, $\eta^2_p = 0.68$), Body Coordination ($F_{1,22} = 74.63$, $p < 0.001$, $\eta^2_p = 0.77$), Strength and Agility ($F_{1,22} = 72.12$, $p < 0.001$, $\eta^2_p = 0.77$). Statistical analysis detected large effect sizes for all significant interactions ($\eta^2_p \geq 0.14$).

As for the intervention group, the post-hoc analyses revealed a significant improvement in scores from pre- to post-test for the Total Motor Composite ($t(11) = 10.77$, $p < 0.001$, $d = 3.84$), Manual Coordination ($t(11) = 6.76$, $p < 0.001$, $d = 1.96$), Body Coordination ($t(11) = 9.25$, $p < 0.001$, $d = 2.66$), and Strength and Agility ($t(11) = 10.14$, $p < 0.001$, $d = 2.88$). Significant differences from pre- to post-intervention were relevant as effect size was found to be large ($d \geq 0.80$). Participants in the control group showed no significant pre-test to post-test changes.

**b. BRIEF**

Statistical analysis revealed significant interactions in 'Time x Group' differences for the Behavior Regulation Index ($F_{1,22} = 19.87$, $p < 0.001$, $\eta^2_p = 0.47$), Emotion Regulation Index ($F_{1,22} = 55.16$, $p < 0.001$, $\eta^2_p = 0.71$), Cognitive Regulation Index ($F_{1,22} = 6.37$, $p = 0.019$, $\eta^2_p = 0.22$) and Global Executive Functioning Composite ($F_{1,22} = 10.34$, $p = 0.004$, $\eta^2_p = 0.32$). Large effect sizes were evident for all significant interactions ($\eta^2_p \geq 0.14$).

The post-hoc analysis revealed significant decreases in scores from pre- to post-testing for the Behavior Regulation Index ($t(11) = -4.12$, $p = 0.002$, $d = 1.18$), Emotion Regulation Index ($t(11) = -9.86$, $p < 0.001$, $d = 2.68$), Cognitive Regulation Index ($t(11) = -6.41$, $p < 0.001$, $d = 1.78$) and Global Executive Functioning Composite ($t(11) = -2.93$, $p = 0.014$, $d = 0.84$) in the intervention group, whereas no there were significant changes across time among participants in the control group. Intervention group differences from pre- to post-intervention showed large effect sizes ($d \geq 0.80$).

## 4. Discussion

The purpose of this study was to examine the impact of Multilateral Training on motor skill proficiency and EF in children with ASD, aged 8-11 years. Following the 12-week Multilateral Training program, intervention participants, compared to participants in the control group, demonstrated enhanced motor performance on the BOT-2 and improved observed executive functioning through their parents' completion of the BRIEF. We found a significant effect of the intervention, with large effect size improvements in the experimental group, compared to the control group in the total motor composite and three motor-area composites (i.e. manual coordination, body coordination, and strength and agility) of the BOT-2 and in the Global executive functioning composite and three indices of EF performance (i.e. Behavior regulation, Emotion regulation and Cognitive regulation) on the BRIEF. Intervention participants show high treatment adherence (91.0%), and all parents expressed a wish to have their children continue the Multilateral Training program after the intervention.

Some other studies with children with ASD have also found improvements in motor skills following physical activity interventions (Bass et al., 2009; Bremer et al., 2015; MacDonald et al., 2012; Pan, 2010; Pan et al., 2017; Wuang et al., 2010). Our finding of large effect size improvements in motor performances of manual and body coordination, running speed, agility, and strength may be due to a series of objective-oriented, structured, progressive activities within the Multilateral Training approach. Only a measure of fine manual control failed to improve after the intervention. This motor skill involved precise hand and finger control, and the ability to reproduce drawings of geometric shapes. While a larger participant sample or longer intervention might have been associated with improvements in this motor proficiency index, even our short intervention led participants to utilize body feedback to understand the outcome of their movements, utilize feedforward information to anticipate upcoming events, utilize flexibility to plan alternative strategies. These significant motor skill enhancements following the intervention may be beneficial for the overall functioning of children with ASD, as MacDonald et al. (2013, 2014) found that children with superior motor skills were also more likely to have better social communication skills. Improved motor skills of children with ASD in this study may later be associated with greater opportunities for social-communicative interactions (e.g., playing with peers) (Bhat et al., 2011; Leary & Hill, 1996). In fact, Multilateral Training included direct opportunities to learn better social interaction skills through game playing. While children and adolescents with ASD generally prefer solitary hobbies and activities that require less physicality, and may involve screen time (Stiller & Mößle, 2018), Multilateral Training can be a valid alternative intervention to prevent these sedentary behaviors and motivate children with ASD to participate in sports activities that require social interaction, communication, cooperation, assertion, responsibility, empathy, engagement, and self-control.

Our findings are consistent with previous studies that support the beneficial effects of physical activity and/or physical activity with game playing on EF among children with ASD (Bahrami et al., 2012; Chan et al., 2013; Hilton et al., 2014; Pan et al., 2017; Toscano et al., 2018; Tsai et al., 2012). For example, Hilton et al. (2014), also using the BRIEF to measure EF, found improvements in working memory and metacognition (i.e. the ability to initiate, plan, organize, and sustain future-oriented problem solving in working memory) among children with ASD after 10 weeks of exergaming (i.e. Makoto arena training), and Tsai et al. (2012) reported a significant increase in the inhibitory function of 16 children with developmental coordination disorder after 10 weeks of soccer training. In this study, the Multilateral Training program, consisting of four progressive levels to train motor skills and require increasingly complex cognitive processes and the inclusion of regular game playing socialization significantly and meaningfully (i.e., with a large effect size) decreased the children's behavioral inhibition, emotional self-regulation and cognitive regulation indices of the BRIEF. Active training in these three core aspects of EF (i.e. behavioral inhibition, working memory and cognitive flexibility) within Multilateral Training consisted of manipulating the task (e.g. the colors, direction, interval, and speed of the balls) and the social environment (e.g. peers and instructors), and the resultant improvements in flexibility may be a basis for further improvements in early repetitive and inflexible behaviors associated with ASD (Geurts, Corbett, & Solomon, 2009). Thus, our Multilateral Training intervention may serve as a valuable addition to other forms of therapy for impaired EF among children with ASD.

Limitations of this study should be recognized. First, we did not consider gender differences in our intervention and control groups because the number of female participants in our study was limited. This should be a focus of future research, however, as a previous study found that females showed greater EF problems than males, with markedly worse adaptive daily living skills (White et al., 2017). Second, parents in this study were not blind to the condition their child was assigned to, and their reporter bias may have been a source of variance on the BRIEF, a parent-report measures. Parents may have been grateful for the attention being shown to their children and inclined to report improvement related to their direct knowledge of their child's participation in this training. An improvement on this study may have been to obtain additional BRIEF ratings from another adult very familiar with the children who had no knowledge of their participation in the intervention. Third, the present study relied only on parental reports of EF and did not include supplemental laboratory EF performance measures; future work should combine laboratory and informant-based EF measures. Fourth, the exclusive use of the BOT-2 for measuring motor skills limited the range of motor skills we assessed. Fifth, investigating additional outcomes such as improved social skills may yield useful findings. Previously, Bass et al. (2009) found improved social functioning in children with ASD after a 12-week horseback riding intervention, and Pan (2010) found improvements in social behaviors in children with ASD after 10 weeks of aquatic group exercise. Finally, it will be important in future research to study and rank order the various components of Multilateral Training that may be responsible for children's gains. While not an emphasis in this Multilateral Training, game playing may have had importance for social and EF gains.

Despite its limitations, this study was the first to evaluate Multilateral Training as a means of delivering motor skills training directed toward both motor skill proficiency and EF among children with ASD. Previous studies demonstrated the effectiveness of Multilateral Training in improving physical fitness and motor skill competency only among typically developing children (Fischetti & Greco, 2017; Greco et al., 2019). Our findings extend the existing Multilateral Training literature by examining both motor proficiency and EF directed toward children with ASD. Furthermore, this study contributes to a limited number of treatment efficacy studies linking EF and ASD symptomology. Intervening with children with ASD through physical recreational programs can be of high scientific and clinical importance. Our large effect size findings amidst a randomized controlled research design paves the way for both further study and practical assistance for these children.

## 5. Conclusion

In summary, we found that school-aged children with ASD who participated in a 12-week Multilateral Training program, consisting of progressive motor skills training and demands for increasingly complex cognitive and social processes, showed enhancements in both motor skills proficiency and EF. Following a Multilateral Training intervention, children with ASD showed greater motor competence such as manual coordination, body coordination, and strength and agility, and better executive functioning in cognitive flexibility, inhibitory control, and working memory. Since ASD is a broad economic and societal problem affecting individuals, families, and communities, practical interventions like Multilateral Training embedded within physical recreation can represent an alternative or complementary therapeutic intervention for children with ASD.

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