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Effects of fundamental movement skills intervention for children with and without autism spectrum disorders

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ABSTRACT

Purpose: The purpose of this study was to confirm the effectiveness of fundamental movement skills (FMS) intervention for younger children with autism spectrum disorders (ASD).
Methods: Ninety-two participants, with the mean age = 6.39 years, attended the present study. Among them, 23 ASD and 23 typically developing (TD) participants were in the exercise groups (ASD-FMS and TD-FMS), receiving 60 min of FMS training twice a week for 12 weeks. Another 23 ASD and 23 TD participants were in the control groups (ASD-C and TD-C). The Test of Gross Motor Development was to assess changes in motor skills. A two-way (Disability x Intervention) ANCOVA was used to control for baseline performance differences.
Results: TD participants initially had better FMS than those with ASD. After the intervention, both the ASD-FMS and TD-FMS groups improved their locomotor and object control skills. However, the TD-FMS group did not show improvement in specific skills like running, leaping, striking, kicking, and forward rolling when compared to the TD-C. Despite this, the TD-FMS group still outperformed the ASD-FMS group in striking and forward rolling. Notably, the ASD-FMS group made significant progress and achieved skill levels in running, leaping, and kicking that were similar to those of the TD-FMS group.
Conclusion: The intervention positively impacted FMS in young children with ASD and their TD peers. The findings suggest that early intervention is crucial, and future research should consider larger sample sizes, teaching aids, and participants' backgrounds for more comprehensive results.

Fundamental movement skills (FMS) are a set of gross movement patterns that involve different body parts. These skills are considered fundamental because they represent the building blocks for more complex skills that children use to navigate the environment (Zeng et al., 2019) and to participate in games, sports, and recreational activities to maintain an active lifestyle across their lifespan (Stodden & Goodway, 2007). FMS can be broken down into locomotor (e.g., running, hopping, jumping, leaping),

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object-control (e.g., throwing, catching, kicking, striking), and stability (e.g., balancing, twisting) skills. Locomotor skills are movements that involve pushing the body from one place to another. Object-control skills are movements that manipulate an object (e.g., a ball or a bean bag) by hands, and/or feet. Stability skills are movements that keep the body in place, both static and dynamic. Stability skills are also needed to progress to locomotor and manipulative skills. Past literature has indicated that the mastery of FMS can contribute to children's physical (O'Brien et al., 2016), cognitive (Schott & Holfelder, 2015), and social development (Yu et al., 2016). To date, performance in the Test of Gross Motor Development, (second edition (TGMD-2), Ulrich (2000))) has been widely used to represent the mastery of FMS. The TGMD-2 is a process-oriented FMS assessment tool that includes six locomotor skills (run, hop, slide, gallop, leap, and horizontal jump) and six object control skills (striking a stationary ball, stationary dribble, catch, kick, overhand throw, and underhand roll). A systematic review of global levels of FMS mastery among children and adolescents at present seems to indicate "below average" to "average" level performance, particularly when compared to typically developing (TD) samples (Bolger et al., 2021). Lloyd et al. (2014) reported that FMS during an early age is positively associated with leisure-time physical activity during young adulthood. Therefore, the implementation of FMS intervention in early childhood is critical. Children at an early age are at an optimal time for developing competent movements. Globally, it is estimated that about 1 in 100 children has autism spectrum disorder (ASD) (Zeidan et al., 2022). As characterized in the Diagnostic and Statistical Manual of Mental Disorders-Fifth Edition (DSM-5-TR), ASD diagnosis criteria include individuals with a predominant difference in social communication skills, and repetitive behaviors, intense or special interests, or sensory sensitivities. (American Psychiatric Association, DSM-5 Task Force, 2013). Although the DSM criteria do not specifically consider motor development in ASD, various standardized measures are used and indicated that about 39% to 87% of a large sample of children with ASD are at risk for motor impairment (Bhat, 2020; Green et al., 2009; Licari et al., 2020). Moreover, there is growing evidence suggesting children with ASD exhibit delays in FMS, particularly when compared to their TD peers and other children with developmental disabilities (Liu & Breslin, 2013; Pan et al., 2009). Impairment in motor skills can also be associated with social-communication symptoms in ASD. Previous research has consistently shown a relationship between impairments in motor and social communication skills (Haswell et al., 2009; Holloway et al., 2018; Gandotra et al., 2020). Furthermore, motor skills impairments that precede may even exacerbate social-communicative symptoms in ASD. Sacrey et al. (2015) have noted that parental concerns regarding an infant's motor development at six months of age could be a significant predictor of ASD diagnosis when infants reach three years of age. A potential interpretation could be that the young brain undergoes many changes in neural structures and functions during this period, particularly at a time when both motor and social tasks require a higher degree of inter-hemispheric coordination. Therefore, starting from a consideration that the significant motor difficulties experienced by children with ASD may start at a young age, we believe early interventions targeting FMS may enhance sensory-motor control and higher social functions in children and adults with ASD.

To date, Healy et al. (2021) conducted a review and systematic review of FMS interventions in children with ASD, and only 22 studies qualified for a full-text review. Furthermore, the literature reports that FMS can be improved through motor interventions in older children (aged 9–12) with ASD. In order to provide evidence for developing more tailored interventions that can address the specific needs of younger (aged below 9) children with ASD, the present study would focus on the effectiveness of FMS interventions for these children. Another point to consider in FMS research is that most existing studies have been conducted in Western countries which often feature different cultural, educational, and societal contexts. Barnett et al. (2019) observed the impact of cultural background on FMS and reported Asian-speaking children had lower object control skills compared to English-European children. Sung (2022) further highlighted that parents of children with ASD in the US rated their children's fine and gross motor skills as better than those rated by parents of children with ASD in Taiwan. Since a person's cultural background can significantly influence their development of FMS (Zeng et al., 2019), it is crucial to expand research into Asian-speaking populations to address the gap in knowledge and provide a more global understanding of how children with ASD develop motor skills in different cultural contexts. Furthermore, studies commonly recruited another group of children with ASD as the control group. Healy et al. (2021) noted a lack of typically developing participants in a control group who did not receive FMS intervention. Without TD participants, it was clear that the results could not truly differentiate the effectiveness of FMS interventions. In contrast, the present study would recruit two additional groups of TD children into exercise and control groups. This comparative approach can provide valuable insights into how children with ASD respond to FMS interventions relative to TD children, and whether these interventions can help bridge the motor skills gap between the two groups. Additionally, different measurement tools (e.g., TGMD-2, Bruininks-Oseretsky Test of Motor Proficiency, 2nd edition, Movement Assessment Battery for Children- 2nd edition, Peabody Developmental Motor Scales, 2nd edition) were used to measure FMS in ASD. Among these, however, TGMD-2 was reported as the most psychometrically appropriate in children with ASD (Downs et al., 2020). Hence, the use of TGMD-2 will provide more accurate and reliable data to evaluate the effectiveness of FMS interventions.

Overall, the purpose of this study was to confirm the effectiveness of FMS intervention in both younger children with ASD and TD peers within the context of an Asian-speaking population. The TD children were included as a comparison group. By including two groups of children with ASD and TD children in both exercise and control conditions, the study aims to not only assess the effectiveness of FMS interventions in children with ASD, but also to compare their progress with that of their TD peers. TGMD-2 was used as the assessment tool to investigate the changes in FMS. It was hypothesized that the children with ASD and TD in the exercise groups would improve FMS after the intervention, and no changes in the control groups would be noted. Further, individual motor skills that constitute locomotor and object control skills would be reviewed, and individual motor skills would be improved in children with ASD and TD in the exercise groups but not in the control groups.

Methods

Participants

A total of ninety-two participants (aged 3.75–10.83 years; mean age = 6.39 ± 1.62 years), attended the present study (see Table 1). Twenty-three participants with ASD and 23 TD participants were assigned to the exercise groups (ASD-FMS and TD-FMS) that would receive FMS intervention; 23 participants with ASD and 23 TD participants were assigned into the control groups (ASD-C and TD-C) that did not receive any additional training during the study. Participants with ASD were diagnosed based on the DSM-5-TR (American Psychiatric Association, DSM-5 Task Force, 2013) by a child psychiatrist or hospital physician. The level of severity was mild, based on social adaptive functioning in skill areas and in language comprehension and expression (Taiwan Disability Information Network, Levels of disability, https://disable.yam.org.tw/archives/1377).

All participants with ASD attended inclusive schools and were assigned to the resource room on a regularly scheduled basis to receive special education services while continuing their other studies in regular classrooms during most of each school day. Some of them also regularly received after-school occupational therapy (n = 2), group therapy (n = 2), and speech therapy (n = 1). Four manifested diagnosed associated conditions such as ADHD, and two were on medication to relieve symptoms. After-school occupational therapy consisted of sensory motor integration and general skill building for participating in activities of daily living, play and school; group therapy involved speaking freely in a group, providing feedback to others, learning each other's manners of interacting, and requesting support; speech therapy involved language comprehension, expression, and communication training. All reside in urban settings and live in a two-parent household.

Fig. 1 shows the procedure of the present study. All protocols were approved by the Human Subjects Institutional Review Board of the university and clinical trial registered on the Australian New Zealand Clinical Trials Registry (ANZCTR) (Registration number: ACTRN 12623000742673).

Measure

The second edition of the Test of Gross Motor Development (TGMD-2; Ulrich, 2000) was chosen to assess participants' FMS in the present study. TGMD-2 consists of two subtests. The locomotor skill subtest measures run, gallop, hop, leap, horizontal jump, and slide skills, and the object control skill subtest measures striking a stationary ball, stationary dribble, catch, kick, overhand throw, and underhand roll skills. The test was administrated at the baseline (T1) and the posttest (T2) after the FMS intervention by following the standard protocol outlined in the test manual (Ulrich, 2000). The testing sessions were video recorded and scored later. Each skill had 3 to 5 performance criteria. Participants scored "1" for successful movement execution or "0 "for the failed attempt of the specific performance criteria.

After scoring, the raw score was calculated by the total number of scored performance criteria. The maximum raw scores for the locomotor and object control subtests were 24 points, respectively. Higher scores represented participants who performed well in locomotor and/or object control skills. The TGMD-2 manual states that it has high test-retest reliability results for locomotor raw scores and object control raw scores for evaluating gross motor performance in children aged from 3 to 10 years (r = .86 −.96). TGMD-2 is also widely accepted for its high validity factor (i.e., content validity, criterion-predictivity, construct validity, and discriminative validity; Eddy et al., 2020; Ulrich, 2000). Thus, the measured outcomes were expected to reflect the quality of the movement patterns and provide detailed information for further interventions. As noted in Table 1, it indicated participants' characteristics in ASD-FMS, ASD-C, TD-FMS, and TD-C groups.

FMS Intervention

Exercise Groups. All participants attended a 12-week period of FMS intervention. The intervention ran 2 sessions/week, 60 min/day over a 12-week-long. Each intervention session was conducted in the gymnasium. All sessions were conducted by the primary investigator with 11 trained research assistants. The primary investigator had a Ph.D. degree majoring in Adapted Physical Education and had more than 20-year experiences working with children with ASD. Research assistants were undergraduate and graduate

Table 1
Descriptive characteristics and outcome variables at baseline measures (T1).

	ASD (n = 46)				TD (n = 46)				Between-group	
	1. ASD-FMS (n = 23)		2. ASD-C (n = 23)		3. TD-FMS (n = 23)		4. TD-C (n = 23)		difference	
	M	SD	M	SD	M	SD	M	SD	F (3,88)	p
Age (years)	6.23	1.88	6.30	1.58	6.56	1.30	6.47	1.75	0.20	.898
Height (cm)	118.46	13.09	118.99	8.64	120.90	5.02	119.47	8.75	0.21	.891
Weight (kg)	23.00	6.96	24.22	7.51	26.64	13.16	23.18	5.05	0.85	.470
BMI (kg/m^2)	16.05	1.83	16.74	2.94	17.21	4.36	16.16	2.59	0.71	.546
Locomotor-T1	29.39	6.56	29.61	5.73	33.43	4.82	34.17	4.65	4.79	.004
Object control-T1	27.13	10.32	28.00	5.66	33.00	5.55	32.70	5.74	4.29	.007

Note. ASD = autism spectrum disorder; TD = typical development; FMS = fundamental movement skills; C = control; BMI = body mass index

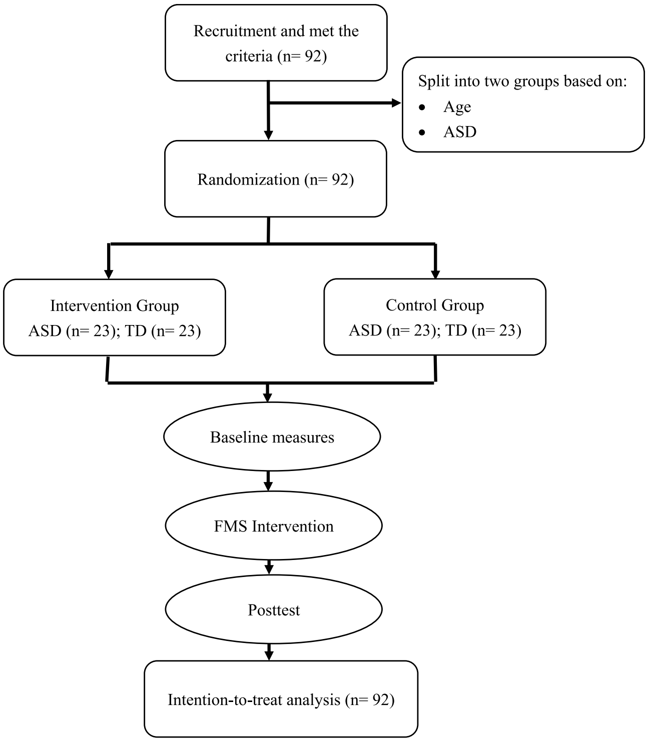

Fig. 1. Participant flow diagram describing the progress through enrollment, allocation, and data analysis.

students from the Physical Education Teacher Education. The primary investigator trained one primary coach and 10 research assistants and provided a written treatment protocol for administering the intervention.

Each session consisted of four components including a warm-up, a review of previously learned skills, instruction and practice of new skills, and a cool-down. Skills that were taught by following the order: balance, running, underhand rolling and throwing, galloping, leaping, sliding, jumping (vertical and horizontal), dribbling/bouncing, overhand throwing, catching, hopping, kicking, and striking. Instruction focused on one skill each week, with progressive difficulty levels, if necessary, throughout the two blocks of intervention (i.e., beginning with balance and ending with striking). Each intervention session was conducted in groups, assisted by a trained undergraduate and graduate research assistants; the instructor-to-child ratio for both groups ranged from 1:2 to 1:3.

The teaching strategies used in the present study are consistent with Breslin and Liu's (2015) best practice guidelines for teaching physical activities to children with ASD. Verbal encouragement was provided to all participants throughout the sessions. The instruction would emphasize the learning process instead of movement outcomes. After each session, the information sheet was also provided to the parents with details on the skill taught that day. All participants completed the 12-week intervention and two measurements. No participants dropped out the study.

Control Groups. The control groups did not receive any instructions and were requested to maintain their original schedules and activities during the intervention.

Data Analysis

Statistical analysis was performed using SPSS 28.0 (SPSS Inc., Chicago, IL, USA). All measurements and calculated values are expressed as mean ± SD. We compared the mean values of each motor skill and overall performance (locomotor skills and object control skills) between exercise and control groups at baseline (T1) by one-way ANOVA. The results of one-way ANOVA found that there were significant differences between groups at the baseline (T1) (as seen in Table 1). In the following analysis, the two-way ANCOVA (2 (Disability: ASD and TD) x 2 (Intervention: FMS and Control) was used to examine the interaction of Disability and Intervention on FMS with adjustment for the covariate of measures at baseline (T1). The alpha level for testing significance was set at $p < .05$. All statistical analysis was performed using SPSS 28.0 (SPSS Inc., Chicago, IL, USA). Partial eta-squared values (ηp^2) were used as measures of effect size and magnitude. According to Cohen (1988), the ηp^2 value between.01 and.06 is a small effect, between.06 and.14 is a medium effect, and 0.14 and above is a large effect.

Results

Comparison of anthropometric characteristics and FMS at baseline measures (T1)

Anthropometric characteristics

The analysis of variance showed that differences in age, height, weight, and body mass index (BMI) across four groups (ASD-FMS, ASD-C, TD-FMS, and TD-C) did not reach significant levels, age: F (3,88) = .20, p = .898, height: F (3,88) = .21, p = .891; weight F (3,88) = .85, p = .470; BMI: F (3,88) = .71, p = .546. This confirmed that there was no difference among ASD-FMS, ASD-C, TD-FMS, and TD-C.

FMS at baseline (T1)

The analysis of variance evaluated the differences in locomotor and object control at baseline (T1) across four groups: ASD-FMS, ASD-C, TD-FMS, and TD-C. First, TD participants (TD-FMS: 33.43 ± 4.82 and TD-C: 34.17 ± 4.65) significantly performed better than ASD participants (ASD-FMS: 29.39 ± 6.56 and ASD-C: 29.61 ± 5.73), F (3,88) = 4.79, p = .004. Additionally, TD participants (TD-FMS: 33.00 ± 5.55 and TD-C: 32.70 ± 5.74) significantly outperformed ASD participants (ASD-FMS: 27.13 ± 10.32 and ASD-C: 28.00 ± 5.66), F (3,88) = 4.29, p = .007. Lastly, TD participants (TD-FMS: 98.96 ± 11.28 and TD-C: 95.04 ± 12.12) significantly had better performance than ASD-C (88.13 ± 11.64) but not ASD-FMS (93.20 ± 10.79), F (3,88) = 3.53, p = .018.

Comparison of overall performance between groups at baseline and posttest

Table 2 indicated the raw scores at baseline (T1) and posttest (T2) for the locomotor skills and object control skills in ASD-FMS, ASD-C, TD-FMS, and TD-C groups.

Locomotor skills

The two-way (Disability x Intervention) ANCOVA with baseline measures as a covariate indicated that, as shown in Table 3, there was a significant main effect of disability on locomotor skills after controlling for baseline measures, F (1,87) = 25.17, $p < .001$, $\eta_p^2 = .22$. TD participants (38.02 ± 0.79) had better locomotor skills than ASD participants (32.25 ± 0.79). There was also a significant main effect of intervention on locomotor skills after controlling for baseline measures, F (1, 87) = 54.55, $p < .001$, $\eta_p^2 = .39$. FMS group (39.08 ± 0.76) had better locomotor skills than control group (31.18 ± 0.76).

Furthermore, there was a significant interaction effect of disability and intervention on locomotor skills after controlling for baseline measures, F (1, 87) = 4.47, p = .037, $\eta_p^2 = .05$. After the intervention, ASD-FMS (36.17 ± 7.29) had better locomotor skills than ASD-C (29.39 ± 6.56), F (1,44) = 25.42, $p < .001$, and TD-FMS (41.74 ± 2.82) had better locomotor skills than TD-C (33.43 ± 4.82), F (1,44) = 14.62, $p < .001$. Overall, TD participants had better locomotor skills than ASD participants whether they received the FMS intervention (TD-FMS >ASD-FMS, F (1,44) = 11.66, p = 0.01) or not (TD-C > ASD-C, F (1,44) = 33.40, $p < .001$).

Object control skills

There was a significant main effect of disability on object control skills after controlling for baseline measures, F (1,87) = 28.66, $p < .001$, $\eta_p^2 = .25$. TD participants (35.48 ± 0.69) had better object control skills than ASD participants (30.09 ± 0.69). There was also a significant main effect of intervention on object control skills after controlling for baseline measures, F (1, 87) = 63.09, $p < .001$, $\eta_p^2 = .42$. FMS group (36.52 ± 0.67) had better object control skills than control group (29.05 ± 0.67).

Furthermore, there was a significant interaction effect of disability and intervention on object control skills after controlling for baseline measures, F (1, 87) = 4.54, p = .036, $\eta_p^2 = .05$. As noted in Table 3, after the intervention, ASD-FMS (32.52 ± 10.05) had better object control skills than ASD-C (23.70 ± 5.97), F (1,44) = 13.30, p = .001, and TD-FMS (40.30 ± 3.99) had better object skills than TD-C (34.61 ± 6.45), F (1,44) = 12.96, p = .001. Overall, TD participants had better object control skills than ASD participants weather they received the FMS intervention (TD-FMS >ASD-FMS, F (1,44) = 11.9-, p = .001) or not (TD-C > ASD-C, F (1,44) = 35.44, $p < .001$).

Table 2
FMS measures between groups at baseline measures (T1) and posttest (T2).

	ASD (n = 46)				TD (n = 46)			
	1. ASD-FMS (n = 23)		2. ASD-C (n = 23)		3. TD-FMS (n = 23)		4. TD-C (n = 23)	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Locomotor								
T1	29.39	6.56	29.61	5.73	33.43	4.82	34.17	4.65
T2	36.17	7.29	26.13	6.17	41.74	2.82	36.48	5.97
Object control								
T1	27.13	10.32	28.00	5.66	33.00	5.55	32.70	5.74
T2	32.52	10.05	23.70	5.97	40.30	3.99	34.61	6.45

Note. ASD = autism spectrum disorder; TD = typical development; FMS = fundamental movement skills; C = control; GMDQ = gross motor development quotient.

Table 3
Summary of the two-way (Disability x Intervention) ANCOVA with baseline measures as a covariate.

	Disability (D)		ASD	TD	Intervention (I)		FMS	C	D x I	
	F (1, 87)	η_p^2	*M* ± *SE*	*M* ± *SE*	*F* (1, 87)	η_p^2	*M* ± *SE*	*M* ± *SE*	*F* (1, 87)	η_p^2
LM-T2	25.17 * *	.22	32.25 ± 0.79	38.02 ± 0.79	54.55 * *	.39	39.08 ± 0.76	31.18 ± 0.76	4.47 *	.05
OC-T2	28.66 * *	.25	30.09 ± 0.69	35.48 ± 0.69	63.09 * *	.42	36.52 ± 0.67	29.05 ± 0.67	4.54 *	.05

Note. ASD = autism spectrum disorder; TD = typical development; FMS = fundamental movement skills; C = control; LM = locomotor; OC = object control; GMDQ = gross motor development quotient; T2 = posttest.

Comparison of each motor skill between groups at baseline measures (T1) and posttest (T2)

Table 4 indicated the raw scores at baseline (T1) and posttest (T2) for each motor skill in ASD-FMS, ASD-C, TD-FMS, and TD-C groups.

Run

There was a significant main effect of disability on the run motor skill after controlling for baseline measures, *F* (1,87) = 4.88, $p = .03$, $\eta_p^2 = .05$. TD participants (6.57 ± 0.19) had a better run motor skill than ASD participants (5.97 ± 0.19). There was also a significant main effect of intervention on the run motor skill after controlling for baseline measures, *F* (1,87) = 29.74, $p < .001$, $\eta_p^2 = .26$. FMS group (6.97 ± 0.18) had a better run motor skill than control group (5.57 ± 0.18).

Furthermore, there was a significant interaction effect of disability and intervention on the run motor skill after controlling for baseline measures, *F* (1,87) = 13.41, $p < .001$, $\eta_p^2 = .13$. After the intervention, ASD-FMS (6.65 ± 1.94) had a better run motor skill than ASD-C (4.61 ± 1.59), *F* (1,44) = 15.23, $p < .001$. However, there was no significant difference between TD-FMS (7.09 ± 1.20) and TD-C (6.74 ± 1.54), *F* (1,44) = 0.73, $p = .399$. Moreover, after intervention, TD-FMS did not have significant better run motor skills than ASD-FMS, *F* (1,44) = 0.83, $p = .367$. As for the control groups, TD-C had a better run motor skill than ASD-C, *F* (1,44) = 21.28, $p < .001$).

Leap

There was a significant main effect of disability on the leap motor skill after controlling for baseline measures, *F* (1,87) = 15.96, $p < .001$, $\eta_p^2 = .16$. TD participants (5.58 ± 0.12) had a better leap motor skill than ASD participants (4.88 ± 0.12). There was also a significant main effect of intervention on the leap motor skill after controlling for baseline measures, *F* (1,87) = 43.95, $p < .001$, $\eta_p^2 = .28$. FMS group (5.80 ± 0.12) had a better leap motor skill than control group (4.65 ± 0.12).

Furthermore, there was a significant interaction effect of disability and intervention on the leap motor skill after controlling for baseline measures, *F* (1,87) = 21.30, $p < .001$, $\eta_p^2 = .20$. After the intervention, ASD-FMS (5.78 ± 0.85) had a better leap motor skill than ASD-C (3.91 ± 1.20), *F* (1,44) = 37.05, $p < .001$. However, FMS intervention did not exert a positive effect because there was no significant difference between TD-FMS (5.87 ± 0.55) and TD-C (5.35 ± 1.27), *F* (1,44) = 3.29, $p = .076$. Moreover, after intervention, TD-FMS had a similar level of leap motor skill as ASD-FMS, *F* (1,44) = 0.17, $p = .682$. As for the control groups, TD-C had a better leap motor skill than ASD-C, *F* (1,44) = 15.54, $p < .001$).

Striking

There was a significant main effect of disability on the striking motor skill after controlling for baseline measures, *F* (1,87) = 8.99, $p = .004$, $\eta p^2 = .09$. TD participants (8.00 ± 0.20) had a better striking motor skill than ASD participants (7.13 ± 0.20). There was also

Table 4
Locomotor and object control skills between and within groups at baseline measures (T1) and posttest (T2).

	ASD ($n = 46$)				TD ($n = 46$)			
	1. ASD-FMS ($n = 23$)		2. ASD-C ($n = 23$)		3. TD-FMS ($n = 23$)		4. TD-C ($n = 23$)	
	T1	T2	T1	T2	T1	T2	T1	T2
Run (8)	5.22 ± 1.62	6.65 ± 1.94	5.65 ± 1.72	4.61 ± 1.59	6.39 ± 1.41	7.09 ± 1.20	6.57 ± 1.47	6.74 ± 1.54
Gallop (8)	4.74 ± 1.25	5.65 ± 1.75	4.52 ± 1.75	4.35 ± 1.70	4.83 ± 1.19	6.61 ± 1.16	4.30 ± 2.05	5.35 ± 2.31
Hop (10)	4.83 ± 1.61	5.83 ± 1.97	4.74 ± 1.91	4.13 ± 1.55	5.09 ± 2.21	7.26 ± 1.68	6.26 ± 1.66	5.78 ± 2.35
Leap (6)	5.22 ± 1.35	5.78 ± 0.85	5.39 ± 0.84	3.91 ± 1.20	5.61 ± 0.94	5.87 ± 0.55	5.26 ± 1.32	5.35 ± 1.27
Jump (8)	4.39 ± 2.17	5.83 ± 1.67	4.61 ± 1.75	4.39 ± 1.20	5.17 ± 1.80	7.13 ± 1.10	4.87 ± 1.89	5.83 ± 1.56
Slide (8)	5.87 ± 1.77	6.43 ± 2.00	5.39 ± 2.23	4.74 ± 1.63	6.35 ± 2.04	7.78 ± 0.42	6.91 ± 1.00	7.43 ± 0.99
Striking (10)	6.65 ± 1.90	7.48 ± 2.00	7.00 ± 2.17	5.87 ± 1.82	8.48 ± 1.16	8.83 ± 1.03	8.17 ± 1.70	8.09 ± 1.65
Catch (6)	3.61 ± 1.53	4.35 ± 1.56	3.87 ± 1.10	2.96 ± 1.07	4.39 ± 1.08	5.22 ± 0.74	4.70 ± 0.70	4.70 ± 0.88
Dribble (8)	2.87 ± 2.88	3.61 ± 3.06	3.00 ± 2.30	3.04 ± 1.82	3.26 ± 2.80	6.17 ± 2.19	2.35 ± 2.55	3.91 ± 2.89
Kick (8)	4.87 ± 1.91	5.87 ± 1.58	5.52 ± 1.59	4.04 ± 1.22	5.83 ± 1.47	6.70 ± 1.26	6.30 ± 1.29	6.22 ± 1.35
Throw (8)	4.26 ± 2.54	5.17 ± 2.76	4.48 ± 1.93	4.17 ± 1.44	5.83 ± 1.67	6.48 ± 1.50	5.87 ± 1.58	5.35 ± 2.21
Roll (8)	4.87 ± 1.74	6.04 ± 1.49	4.57 ± 1.65	4.04 ± 1.82	5.22 ± 1.70	6.91 ± 1.12	5.30 ± 1.77	6.35 ± 1.75

Note. ASD = autism spectrum disorder; TD = typical development; FMS = fundamental movement skills; C = control.

Table 5
Summary of the two-way (Disability x Intervention) ANCOVA with baseline measure as a covariate.

	Disability (D)		ASD	TD	Intervention (I)		FMS	C	D x I	
	F (1, 87)	η_p^2	*M* ± *SE*	*M* ± *SE*	*F* (1, 87)	η_p^2	*M* ± *SE*	*M* ± *SE*	*F* (1, 87)	η_p^2
Run-T2	4.88	.05	5.97 ± 0.19	6.57 ± 0.19	29.74 * *	.26	6.97 ± 0.18	5.57 ± 0.18	13.41 * *	.13
Gallop-T2	9.39 * *	.10	4.98 ± 0.23	6.00 ± 0.23	10.83 * *	.11	6.04 ± 0.23	4.94 ± 0.23	0.09	.00
Hop-T2	9.43 * *	.10	5.18 ± 0.26	6.32 ± 0.26	25.53 * *	.23	6.67 ± 0.26	4.83 ± 0.26	0.24	.00
Leap-T2	15.96 * *	.16	4.88 ± 0.12	5.58 ± 0.12	43.95 * *	.28	5.80 ± 0.12	4.65 ± 0.12	21.30 * *	.20
Jump-T2	19.97 * *	.19	5.18 ± 0.19	6.40 ± 0.19	25.19 * *	.23	6.47 ± 0.19	5.12 ± 0.19	0.27	.00
Slide-T2	38.05 * *	.30	5.76 ± 0.19	7.44 ± 0.19	15.68 * *	.15	7.12 ± 0.19	6.08 ± 0.19	3.49	.09
Striking-T2	8.99 * *	.09	7.13 ± 0.20	8.00 ± 0.20	20.20 * *	.11	8.16 ± 0.19	6.97 ± 0.19	5.72 *	.06
Catch-T2	18.74 * *	.18	3.84 ± 0.15	4.77 ± 0.15	27.78 * *	.24	4.85 ± 0.15	3.76 ± 0.15	4.33 *	.05
Dribble-T2	18.47 * *	.18	3.29 ± 0.30	5.08 ± 0.30	7.93	.08	4.78 ± 0.30	3.60 ± 0.30	1.63	.02
Kick-T2	19.43 * *	.18	5.16 ± 0.17	6.26 ± 0.17	34.14 * *	.28	6.42 ± 0.17	5.00 ± 0.17	8.975 * *	.09
Throw-T2	0.21	.00	5.22 ± 0.22	5.37 ± 0.22	14.63 * *	.14	5.87 ± 0.22	4.71 ± 0.22	0.00	.00
Forward Rolling-T2	22.94 * *	.21	5.19 ± 0.19	6.49 ± 0.19	20.98	.19	6.45 ± 0.19	5.23 ± 0.19	5.24 *	.06

a significant main effect of intervention on the striking motor skill after controlling for baseline measures, $F\ (1{,}87) = 20.20$, $p < .001$, $\eta p^2 = .11$. FMS group (8.16 ± 0.19) had a better striking motor skill than control group (6.97 ± 0.19).

Furthermore, there was a significant interaction effect of disability and intervention on the striking motor skill after controlling for baseline measures, $F\ (1{,}87) = 5.72$, $p < .019$, $\eta p^2 = .06$. In addition, FMS intervention exerted a positive effect in ASD participants. ASD-FMS (7.48 ± 2.00) had a better striking motor skill than ASD-C (6.65 ± 1.90), $F\ (1{,}44) = 8.17$, $p < .006$. However, the positive effect was not seen in TD participants. There is no difference was noted between TD-FMS (8.83 ± 1.03) and TD-C (8.09 ± 1.65), $F\ (1{,}44) = 3.33$, $p = .075$. Moreover, TD participants had a better striking motor skills than ASD participants weather they received the FMS intervention (TD-FMS >ASD-FMS, $F\ (1{,}44) = 8.28$, $p = .006$) or not (TD-C > ASD-C, $F\ (1{,}44) = 18.79$, $p < .001$).

Catch

There was a significant main effect of disability on the catch motor skill after controlling for baseline measures, $F\ (1{,}87) = 18.74$, $p < .001$, $\eta p^2 = .18$. TD participants (4.77 ± 0.15) had a better catch motor skill than ASD participants (3.84 ± 0.15). There was also a significant main effect of intervention on the striking motor skill after controlling for baseline measures, $F\ (1{,}87) = 27.78$, $p < .001$, $\eta p^2 = .24$. FMS group (4.78 ± 0.30) had a better catch motor skill than control group (3.60 ± 0.30).

Furthermore, there was a significant interaction effect of disability and intervention on the striking motor skill after controlling for baseline measures, $F\ (1{,}87) = 4.33$, $p = .04$, $\eta p^2 = .05$. After intervention, ASD-FMS (4.35 ± 1.56) had a better catch motor skill than ASD-C (2.96 ± 1.07), $F\ (1{,}44) = 12.53$, $p = .001$. TD-FMS (5.22 ± 0.74) had a better catch motor skill than TD-C (4.70 ± 0.88), $F\ (1{,}44) = 4.79$, $p = .034$. Moreover, TD participants had a better catch motor skill than ASD participants weather they received the FMS intervention (TD-FMS >ASD-FMS, $F\ (1{,}44) = 8.87$, $p = .02$) or not (TD-C > ASD-C, $F\ (1{,}44) = 36.59$, $p < .001$).

Kick

There was a significant main effect of disability on the kick motor skill after controlling for baseline measures, $F\ (1{,}87) = 19.43$, $p < .001$, $\eta_p^2 = .18$. TD participants (6.26 ± 0.17) had a better kick motor skill than ASD participants (5.16 ± 0.17). There was also a significant main effect of intervention on the kick motor skill after controlling for baseline measures, $F\ (1{,}87) = 34.914$, $p < .001$, $\eta_p^2 = .28$. FMS group (6.42 ± 0.17) had a better kick motor skill than control group (5.00 ± 0.17).

Furthermore, there was a significant interaction effect of disability and intervention on the kick motor skill after controlling for baseline measures, $F\ (1{,}87) = 8.975$, $p = .004$, $\eta_p^2 = .09$. After the intervention, ASD-FMS (5.87 ± 1.58) had a better kick motor skill than ASD-C (4.04 ± 1.22), $F\ (1{,}44) = 19.27$, $p < .001$. However, TD-FMS (6.70 ± 1.26) did not have a significantly better kick motor skill compared to TD-C (6.22 ± 1.35), $F\ (1{,}44) = 1.55$, $p = .220$. Moreover, TD-FMS and ASD-FMS had a similar level of kick motor skill, $F\ (1{,}44) = 3.86$, $p = .056$. As for the control groups, TD-C had a better kick motor skill than ASD-C, $F\ (1{,}44) = 32.82$, $p < .001$).

Forward rolling

There was a significant main effect of disability on the kick motor skill after controlling for baseline measures, $F\ (1{,}87) = 22.94$, $p < .001$, $\eta_p^2 = .21$. TD participants (6.49 ± 0.19) had a better roll motor skill than ASD participants (5.19 ± 0.19). There was also a significant main effect of intervention on the roll motor skill after controlling for baseline measures, $F\ (1{,}87) = 20.98$, $p < .001$, $\eta_p^2 = .19$. FMS group (6.45 ± 0.19) had a better kick motor skill than control group (5.23 ± 0.19).

Furthermore, there was a significant interaction effect of disability and intervention on the roll motor skill after controlling for baseline measures, $F\ (1{,}87) = 5.24$, $p = .06$, $\eta_p^2 = .024$. After the intervention, ASD-FMS (6.04 ± 1.49) had a better kick motor skill than ASD-C (4.04 ± 1.82), $F\ (1{,}44) = 16.60$, $p < .001$ but TD-FMS (6.91 ± 1.12) did not have a significantly better kick motor skill compared to TD-C (6.35 ± 1.75), $F\ (1{,}44) = 1.70$, $p = .199$. Moreover, TD participants had a better roll motor skill than ASD participants weather they received the FMS intervention (TD-FMS >ASD-FMS, $F\ (1{,}44) = 4.98$, $p = .031$) or not (TD-C > ASD-C, $F\ (1{,}44) = 19.17$, $p < .001$).

Discussion

The purpose of this study was to evaluate the effectiveness of FMS intervention in young children with ASD. From overall motor performance, we found that TD participants performed better than ASD participants. After FMS intervention, ASD and TD participants demonstrated improvements in locomotor and object control skills. When it comes to the specific motor skills, TD participants did not improve the run, leap, striking, kick, and forward rolling skills after the FMS intervention. Although striking and forward rolling skills were not significantly improved, TD participants still outperformed ASD participants who received the intervention. On the other hand, ASD participants after the intervention showed substantial improvement and performed similar level of run, leap, and kick skills compared to TD participants.

Comparison of FMS between groups at baseline

Inconsistent with our hypothesis, significant differences in FMS were noted between the ASD and TD participants, which demonstrated that the TD children had better locomotor and object control skills than the young children with ASD. Recent research has reported the presence of motor deficiencies in some children with ASD. Dong et al. (2024) used the Movement Assessment Battery for Children 2 (M- ABC2) in children, aged 7–10 years and reported up to 80 % of children with ASD either displayed motor challenges or were at risk of developing such delays. When compared to their TD peers, children with ASD specifically scored lower in areas of gross motor skills, such as ball skills and balance. Similarly, Licari et al. (2020) examined data from the Western Australia Register and reported that 35 % of young children with ASD, aged below 6 years old, had motor difficulties and a further 43.7 % scored in the moderately low range based on the results of the Vineland Adaptive Behavior Scales. In addition, Liu et al. (2021) have comprehensively examined the gross motor skills among children with ASD between the ages of 7 and 14 by using the Bruininks-Oseretsky Test of Motor Proficiency-2 (BOT-2). Liu et al. (2021) indicated that children with ASD were significantly delayed in many aspects of gross motor skills in upper-limb coordination, bilateral coordination, balance, running speed, strength, and agility compared to their TD peers, with all scoring in the well below average category of the BOT-2. Our findings confirmed that delays in FMS are prevalent in children with ASD because participants with ASD scored below the average category of locomotor and object control skills. In consideration of the well-documented that children with ASD are generally delayed in all aspects of gross motor development, the findings highlight the need for further consideration of motor impairment as a distinct specifier within the diagnostic criteria and evaluation of autism.

Comparison of FMS between groups at posttest

Partially consistent with our hypotheses, some positive effects of FMS intervention were demonstrated in ASD and TD participants. After the intervention, ASD and TD participants significantly improved their overall locomotor and object control skills. Furthermore, ASD participants significantly improved each of their motor skills. Nonetheless, a similar condition was not seen in TD participants. Surprisingly, no significant difference was found in the run, leap, striking, catch, kick, and forward rolling skills between TD-FMS and TD-C groups. First, this study lasted for 12 weeks, TD-C group also made motor improvements due to the natural growth and development of the participants. In addition, TD participants in the control group may have participated in some leisure activities (e.g., basketball, and soccer programs) in their daily lives that contributed to motor development and enhanced their performance during the posttest. On the other hand, the TD-FMS group specifically outperformed in their hopping, jumping, and catching skills. It is important to note that hopping is a more advanced skill than jumping. Participants needed to take off from one foot and land on that same foot. Children between the ages of 5 and 7 generally may show marked improvement in speed, control, and technique. Hence, participants in the present study may have developed their motor ability to maintain balance and control the center of mass and foot

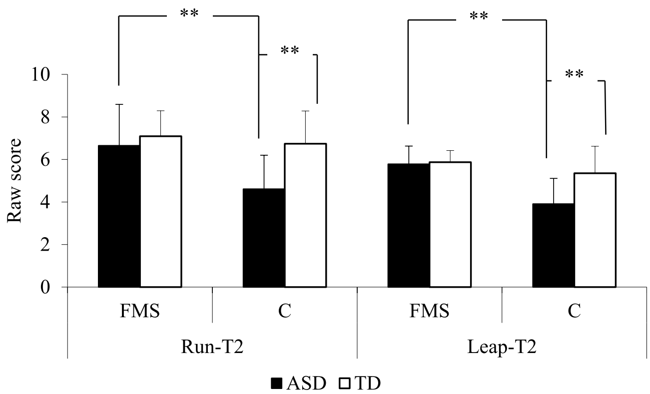

Fig. 2. Group comparisons on locomotor skills at posttest (T2); * p < .05; * * p < .01 (FMS = fundamental movement skills; C = control; ASD = autism spectrum disorder; TD = typical development). Error bars represent standard deviation.

placement during hopping practices (Beerse & Wu, 2016). Hence, it could be interpreted that TD-FMS had done well in the dynamic balance, with the non-hopping side adding counterbalance and force to assist with the continuous forward and upward movements. Additionally, catching could be categorized as a coincidence timing task since it involves anticipating where a ball can be intercepted as well as the ability to complete the movements that position the hands at that location (Peper et al., 1994). After the intervention, TD participants may have developed different strategies to adjust position errors or change hand position to reduce their grasp errors. Overall, improvements in hopping, running, and catching skills resulted in TD participants in the exercise group having better overall motor performance in locomotor and object control skills.

Interestingly, a significant improvement was reported in run and leap skills in ASD-FMS. Fig. 2 shows that their performance showed no significant differences compared to the TD-FMS group. Run and leap are considered part of children's daily movements. In particular, leap is a locomotor movement characterized as an extension of running. Children always run and sometimes use leap techniques in their free play. The performance criteria of the TGMD-2 required participants to leap consecutively for a distance of 10 feet (3.048 m). Participants needed to take off on one foot to have a long flight phase in the air and land on the opposite foot. Thus, the leaping skill seemed to be a more complicated version of the running skill in which a high degree of strength and a finer adjustment were required to coordinate each part of the body. It was assumed that participants with ASD had mastered some elements of running and leaping and were acquainted with these movement sequences leading to successful performance. Therefore, our FMS intervention appeared to contribute as much as to participants' refinement in run and leap movements. Further, a child might use his or her "chosen limb" to perform the task since young children's limb preference is task-specific and age-dependent (Nonis et al., 2006). In the present study, participants' chosen leg may not be the preference in footedness, which was usually referred to as limb dominance. The preference leg is mainly used to perform the motor tasks requiring force (Huurnink et al., 2014); however, the confusion with the non-preference leg from participants may be another confounding factor that led to no differences between ASD-FMS and TD-FMS groups in the present study.

Finally, ASD-FMS group significantly improved their kicking stationary ball skill. kicking skill involves the leg backswing in preparation, stepping with the opposite foot as the body moves forward, and ball contact, along with follow through to the target. After FMS intervention, the improvement in kicking skills might indicate that ASD participants had learned how to adjust the position of the body and feet when controlling or releasing the ball at an optimal position and better understood how to use the arms to maintain effective force production. As a result, ASD participants might carry these benefits to other motor skills, leading to significant changes in overall motor performance. In addition, kicking is a selected sport typically promoted in preschools. Some participants might have already experienced this motor skill or been involved in relevant activities in schools. Hence, as noted in Fig. 3, no significant differences were evident between ASD-FMS and TD-FMS groups due to their past experiences with ball kicking. In addition, the Asian-speaking children had lower object control skills than English-European children (Barnett et al., 2019) and object control skills are positively associated with fitness, physical activity, and sports competence perception. Van der Fels et al. (2015) also noted the relationship between cognitive ability and motor ability. In the present study, different background information, such as race, cognitive ability, ball experiences, physical activity, and physical fitness levels, might be the factors that explain different improvements in ASD and TD participants.

Limitations and future directions

Nonetheless, several limitations should be taken into consideration. Firstly, the movement assessment batteries that were used to measure FMS in children with ASD were designed primarily for TD children, which may not provide a completely accurate representation of FMS in children with ASD. For instance, the verbal method used to give task instructions makes them less acceptable to children with ASD who have inherent difficulties in communication and social interactions. Future research is, therefore, recommended to incorporate and make use of visual aids when assessing movement skills in children with ASD, to help them understand how the tasks are to be carried out (Breslin & Rudisill, 2011). Secondly, our knowledge of the developmental patterns of movement skills in individuals with ASD comes mainly from studies with short-term observations. In future research, a longitudinal examination of the rate of FMS development in individuals with ASD across their lifespan would be valuable. Thirdly, the inclusion of background information (e.g., race, cognitive ability, ball experiences, physical activity, and physical fitness levels) should be considered before FMS intervention. In addition, mid-intervention evaluation and specific measures of effort or exertion could be added in the future studies for quality control. Such information would be able to depict the efficacy of intervention for each population. Finally, the a priori sample size was determined using an effect size of 0.25, with a significance level of 0.05 and a power of 0.80, considering the repeated measures ANCOVA with main effects and interactions. The test was conducted using G*Power software, resulting in a recommended number of 282 participants. Although the sample size was relatively small, the current study's results showed that after FMS intervention, children with ASD not only improved their locomotor and objective control skills but also performed similar levels of certain motor skills compared to their TD peers.

In summary, our preliminary findings contributed to the literature supporting a positive effect of movement intervention on FMS in young children with ASD and their TD peers. It provided fundamental support for the effectiveness and importance of FMS intervention in early intervention. Since early motor skill interventions might enhance later social development, parents, teachers, and therapists should consider the long-term sustainability of FMS interventions for ASD populations.

CRediT authorship contribution statement

Chu-Yang Huang: Data curation, Investigation. **Chien-Yu Pan:** Conceptualization, Formal analysis, Investigation, Methodology,

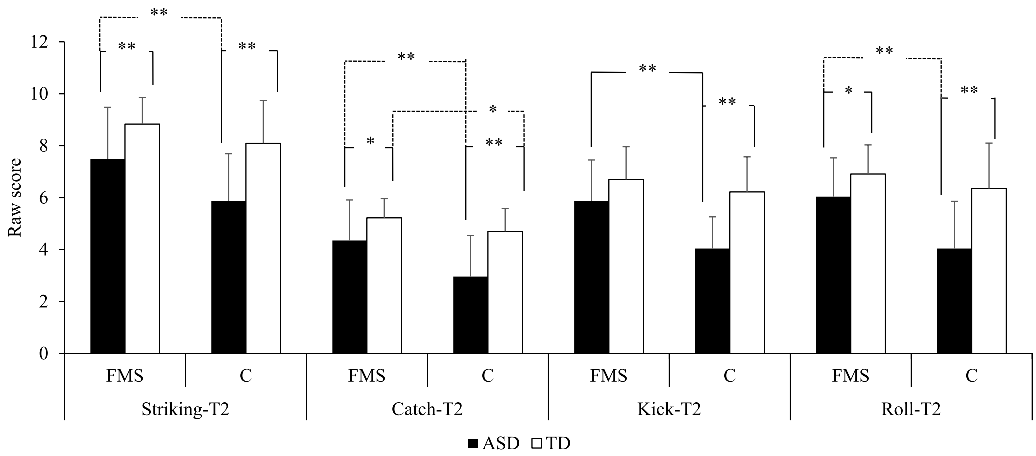

Fig. 3. Group comparisons on object control skills at posttest (T2); * p < .05; * * p < .01 (FMS = fundamental movement skills; C = control; ASD = autism spectrum disorder; TD = typical development). Error bars represent standard deviation.

Supervision, Writing – review & editing. **Chen Chih-Chia:** Writing – original draft, Writing – review & editing, Methodology. **Yung-Ju Chen:** Investigation, Writing – review & editing. **Ming-Chih Sung:** Investigation, Writing – review & editing. **Chia-Lian Tsai:** Conceptualization, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this article.

Data availability

The data that has been used is confidential.

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