Association Between the Skeletal Muscle Mass Index and Physical Function in Adolescents with Intellectual and Developmental Disabilities

Sato, Hiroki ; Akisue, Toshihiro ; Tanemura, Rumi ; Yamamoto, Akio ; Ono, Kumiko ; Uchida, Junko ; Ishida, Junko ; Nagao, Toru

(Citation)
Advances in Neurodevelopmental Disorders

(Issue Date)
2025-03-14

(Resource Type)
journal article

(Version)
Version of Record

Advances in Neurodevelopmental Disorders
https://doi.org/10.1007/s41252-025-00437-1

ORIGINAL PAPER

Association Between the Skeletal Muscle Mass Index and Physical Function in Adolescents with Intellectual and Developmental Disabilities

Hiroki Sato[1] · Toshihiro Akisue[2] · Rumi Tanemura[3] · Akio Yamamoto[1] · Kumiko Ono[1] · Junko Uchida[2] · Junko Ishida[2] · Toru Nagao[2]

Accepted: 29 January 2025

Abstract

Background Children and adolescents with intellectual and developmental disabilities (IDD) often experience reduced health-related physical function. However, the correlation between decline in physical function and reduced limb skeletal muscle mass among adolescents with IDD is not yet clear. This study aimed to clarify the relationship between limb skeletal muscle mass and physical function in adolescents with IDD.

Methods This short-term longitudinal observational study included 53 adolescents (aged 12–18 years) with IDD from special needs schools who attended community sports classes in Kobe City, Japan. The assessment included body composition analysis (skeletal muscle mass index: SMI) and physical fitness tests (handgrip strength, standing long jump, sit-ups, sit-and-reach test, six-minute walk test, pulmonary function tests), complemented by physical activity level questionnaires.

Results Significant positive correlations were observed between SMI and handgrip strength, as well as between SMI and standing long jump performance. The physical fitness assessment showed high reliability upon re-measurement after 4 weeks. Additionally, multiple linear regression analyses considering SMI as the dependent variable and adjusting for age, sex, body mass index, and physical activity level showed significant positive associations for handgrip strength and standing long jump.

Conclusions This study revealed significant associations between skeletal muscle mass index and physical fitness indicators, such as handgrip strength and standing long jump, in adolescents with intellectual and developmental disabilities. These measures may be effective indicators for assessing limb skeletal muscle development in this population.

Keywords Intellectual disability · Developmental disability · Limb skeletal muscle mass index · Body composition · Physical fitness assessment · Adolescents

Introduction

Studies have reported declines in health-related physical fitness and physical function in children and adolescents with intellectual and developmental disabilities (IDD) (Hartman et al., 2015; Salaun & Berthouze-Aranda, 2012). Physical fitness is associated with a reduced risk of metabolic diseases (e.g., metabolic syndrome), obesity, and cardiovascular diseases (Andersen et al., 2008). Compared with typically developing peers, children and adolescents with IDD have lower muscular strength, muscular endurance, exercise tolerance, balance, and aerobic capacity, which may adversely affect their development (Golubović et al., 2012; Wouters et al., 2020). Additionally, children and adolescents with IDD face more chronic illnesses and health issues (Oeseburg et al., 2011). Reduced physical fitness is a risk factor for cardiovascular diseases, diabetes, and poor mental health (Hurtig-Wennlöf et al., 2007). Physical activity is considered important for improving physical functions, but individuals with IDD have lower levels of physical activity compared to those without disabilities. It is recommended

✉ Hiroki Sato
sato.h@people.kobe-u.ac.jp

1 Department of Public Health, Kobe University Graduate School of Health Sciences, 7-10-2, Tomogaoka, Suma, Kobe, Hyogo 6540142, Japan

2 Department of Rehabilitation Science, Kobe University Graduate School of Health Sciences, Kobe, Japan

3 Faculty of Rehabilitation, Kansai Medical University, Osaka, Japan

Published online: 14 March 2025

to enhance opportunities for community outings and to offer direct expert support using a psychosocial approach (Kim & Lee, 2023).

Skeletal muscles are important body tissues with numerous physiological functions. The limb skeletal muscles play a crucial role in movement and posture. Typically, skeletal muscle function peaks between the ages of 20 and 25 years, gradually declining around 50 years, highlighting the importance of physical activity during adolescence and in older age (Tabata et al., 2023). Sarcopenia is the loss of skeletal muscle mass and function due to aging or chronic illness (Janssen et al., 2002; Morley et al., 2001). Recent research has noted the possibility of sarcopenia in younger populations (Kim et al., 2016; Zembura & Matusik, 2022). Factors such as inactivity, inflammation, aging, loss of appetite, and poor nutrition have been reported to affect muscle mass, and these factors vary individually. Although sarcopenia is generally known to occur with aging, it is not confined to older adults. It is a risk factor for insulin resistance and is associated with metabolic risks in children and adolescents (Hurtig-Wennlöf et al., 2007). Furthermore, conditions, such as IDD, have been shown to impact muscle mass significantly (Sung et al., 2020). Unlike obesity, which can be screened simply using weight, height, and waist circumference, the assessment of limb skeletal muscle mass and physical function is not routinely performed for children and adolescents with IDD. Methods such as bioelectrical impedance analysis (BIA), dual-energy X-ray absorptiometry, and CT/MRI are used to measure skeletal muscle mass. Previous studies have confirmed the reliability and validity of BIA in adolescents with IDD (Wouters et al., 2017). However, body composition evaluations, including the convenient BIA method, can still take a few minutes to complete, and maintaining the same posture for long periods or undergoing tests in confined spaces can be challenging for adolescents with IDD. Thus, measuring skeletal muscle mass in many students in a school setting is difficult. When screening adults for sarcopenia, physical function assessments such as handgrip strength, walking speed, the Short Physical Performance Battery, the Timed Up and Go Test (TUG), and the 400-meter walk are commonly employed (Dent et al., 2018). In healthy adolescents, physical function, such as handgrip strength and the six-minute walk test, has been reported to correlate with skeletal muscle mass (Zembura et al., 2023). However, research has not confirmed any correlation between physical function and skeletal muscle mass in adolescents with IDD.

Therefore, we aimed to clarify the relation between limb skeletal muscle mass and physical function in adolescents with IDD and identify predictors of limb skeletal muscle mass. We examined which items of the physical fitness test are strongly related to skeletal muscle mass. Further, we conducted retests to verify reproducibility. This was necessary because, although previous studies have reported reliability in physical fitness measurements for adolescents with IDD (Wouters et al., 2017), sufficient reproducibility of physical fitness tests, particularly those commonly employed in Japan, has yet to be confirmed.

Methods

Study Design and Participants

This short-term longitudinal observational study included students (aged 13-18) who attended special needs junior high and high schools (seven schools) in Kobe City, Japan. These participants enrolled in community sports classes (the Sports Challenge Program). The Sports Challenge Program was designed to provide students with special needs opportunities to participate in sports they might not have participated in before, incorporating both initial and final assessments of their short-term physical functioning. Students participated in the offered activities, such as athletics, tennis, badminton, and dance, based on their preferences. The program was conducted once a week for five weeks, with each session lasting two hours. However, during the first and final sessions, approximately one hour was allocated to measurements with the remaining one hour allocated to program activities. Activities were conducted in small groups of approximately four participants, guided by specialized instructors and assistants. We set the inclusion criterion of IDD documented with a care notebook issued in Kobe City by medical doctors or clinical psychologists, categorized as severe (Intelligence Quotient; IQ up to 35), moderate (IQ 36–50), or mild (IQ 51–75). Our exclusion criteria were lack of consent, missing data for body composition analysis, and concurrent physical disability, such as cerebral palsy. This study was conducted following the Helsinki Declaration and obtained approval from the relevant department of the University. Participants who obtained written consent from their guardians were included. Additionally, research information was made publicly available on the university website, and opportunities for consent withdrawal were ensured. This study was prepared following the STROBE guidelines.

Measurement

We conducted measurements following warm-up exercises during both the initial and final sessions of the sports program in the gymnasium. All measurements were performed following standard protocols, with a focus on safety, by a team comprising experienced physical therapists, occupational therapists, nurses, and rehabilitation students. All tests were conducted after a minimum two-hour fast and included preliminary safety measures, such as the use of blood pressure cuffs and pulse oximeters, following a bathroom visit.

A nurse was present during measurements, which followed a sufficient warm-up. The test was conducted under consistent conditions, on the same day of the week and at the same time, before the start of the sports program. Sufficient rest periods were provided before each measurement, along with adequate practice time to ensure accurate performance of each measurement task. For physical fitness measurements, we selected the handgrip strength, standing long jump, sit-ups, and sit-and-reach test. These assessments demonstrated high reliability in Wouters et al.'s (2017) study and are recommended by the Ministry of Education, Culture, Sports, Science and Technology. The assessments are widely utilized in educational settings in Japan. Additionally, we included a six-minute walk test and a pulmonary function test.

Assessment of Body Composition (Height, Weight, Appendicular Skeletal Muscle Mass)

We measured height without shoes using a portable stadiometer (Seca Portable Stadiometer 213, Muranaka Medical Instruments Co., Ltd., Japan). We used a body composition analyzer (InBody430, InBody Co., Korea) employing the Direct Segmental Multi-Frequency BIA for weight and appendicular skeletal muscle mass measurements. This method utilizes an eight-point contact electrode system measuring impedance at three frequencies (5, 50, and 250 kHz) across five body segments. The measurements followed manufacturer instructions, with participants avoiding skin-to-skin contact. Measurements are conducted with participants in a standing position, requiring them to remain still for several minutes. We calculated the skeletal muscle mass index (SMI) as the appendicular skeletal muscle mass index divided by height squared. Body mass index (BMI) was also calculated by weight divided by height squared.

Physical Activity Level

We assessed the physical activity level using the Japanese version of the WHO Health Behavior in School-aged Children (HBSC) Physical Activity Questions (Tanaka et al., 2017). "Physical activity refers to any movement that increases your heart rate or causes you to feel out of breath. Examples include playing sports, engaging in active play with friends, walking to school, running, brisk walking, roller skating, cycling, dancing, skateboarding, swimming, or participating in activities like soccer, basketball, or surfing. Over the past 7 days, how many days did you engage in at least 60 minutes of physical activity? Please calculate the total time spent on physical activity for each day." Responses were collected orally with visual aids provided by the interviewer, focusing on the weekly days when the children engaged in moderate-to-vigorous physical activity (MVPA). Responses were excluded if participants provided ambiguous answers or were unable to recall adequately.

Physical Fitness Assessment

Handgrip Strength

Handgrip strength is measured to evaluate overall muscle strength. In our study, we assessed handgrip strength using a Smedley-type digital hand dynamometer (Grip-D, Takei Scientific Instruments Co., Ltd., Japan). Participants held the dynamometer with the pointer facing outward and performed the measurement in a standing position. The grip width was adjusted to ensure that the second joint of the index finger formed an approximate right angle. Care was taken to avoid swinging the dynamometer during the measurement process. Each hand was tested twice, and the best records for the left and right hands were averaged separately.

Standing Long Jump

This test is conducted to evaluate explosive power. Begin by standing upright with feet slightly apart, ensuring that your toes are aligned with the front edge of the takeoff line. Perform a forward jump using both feet simultaneously. Measure the distance from the nearest point of contact on the floor or mat after the jump to the center point of both feet at the front edge of the takeoff line before the jump. Repeat the test twice and record the better of the two results.

Sit-Ups

This test assesses core muscle strength and endurance. To perform the test, lie on your back on a mat with your knees bent at a 90° angle. Cross your arms in front of your chest and lightly clasp your hands. An assistant should stabilize your knees throughout the test. At the signal "start," raise your upper body from the supine position until both elbows touch your thighs, then lower your back to the mat to return to the starting position. Perform as many sit-ups as possible within 30 seconds, ensuring each repetition meets the criteria: both elbows must touch the thighs at the top, and the back must fully return to the mat at the bottom. Repetitions that do not meet these requirements are not counted. The test is performed only once.

Sit-and-Reach Test

This test evaluates body flexibility. Arrange two boxes approximately 22 cm wide, 31 cm deep, and 24 cm high parallel to each other, leaving about 40 cm of space between them. Place a cardboard sheet over the boxes and secure it with duct tape. The test subject sits with both legs extended between the boxes in a long-sitting posture, ensuring their back and hips are firmly pressed against the wall. With palms facing down, the subject places their hands so that the center of their palms touches the edge of the cardboard. While keeping their chests open and elbows straight, they push the boxes forward as far as possible, maintaining a straight back. The distance the boxes are moved during the maximum forward stretch is measured using the ruler. The test is performed twice, and the better result of the two attempts is recorded.

Six-Minute Walk Test

Following American Thoracic Society (ATS) guidelines (ATS Committee on Proficiency Standards for Clinical Pulmonary Function Laboratories 2002), this test measured the distance walked in six minutes using a 30-meter straight-line turnaround course. Before the measurement, participants were seated and allowed adequate rest. The evaluation was conducted individually with only the participant and the evaluator present. To ensure comprehension, the evaluator walked one lap of the course alongside the participant before beginning. Participants were then provided with the standardized instruction: “Walk as far as possible within six minutes.” For safety, the evaluator followed behind the participant at a pace that avoided interference. No encouragement was given during the walk, but standardized reminders were provided at one-minute intervals. Results were excluded if participants deviated from the designated course or engaged in prohibited behaviors, such as running.

Pulmonary Function Tests

We assessed pulmonary function using an electronic spirometer (AS-307, AS-407, Minato Medical Science Co., Ltd., Japan), following ATS guidelines (Standardization of spirometry; Graham et al., 2019). The electronic spirometer was pre-calibrated by the supplier. The temperature, pressure, and humidity of the gymnasium were measured and recorded prior to the test. To ensure safety, adequate spacing was maintained between individuals, and infection control measures, including the use of disposable filters, were strictly implemented. All measurements were conducted with the subjects seated. Prior to testing, subjects received detailed instructions, supplemented with photographs, and were given the opportunity to practice the procedure. During testing, subjects wore a nose clip, held the mouthpiece, and initially breathed normally. They were then instructed to take a deep breath quickly and exhale fully. Efforts were made to prevent kyphotic posture during the measurement. Tests were discontinued if air leakage was evident or if the subject had difficulty following the instructions. Up to three attempts were allowed, with the highest recorded value used for analysis. The tests were administered by physical therapists, occupational therapists, or nurses under the supervision of a clinical laboratory technologist.

Statistical Analysis

The data were collected by researchers familiar with statistics and physical fitness measurements. Statistical analyses were performed using EZR 1.55 (Kanda, 2013), with a significance level of $p < 0.05$ set for two-tailed tests. We used descriptive statistics, including means and standard deviations as well as medians and interquartile ranges, to characterize participant demographics and physical fitness measurements. We applied for the Shapiro–Wilk test to assess normality. For normally distributed data, we used Pearson’s correlation coefficients. For non-normally distributed data, we used Spearman's rank correlation coefficients to examine the relationships between SMI and various physical fitness measurements, including handgrip strength, standing long jump, sit-ups, sit-and-reach test, six-minute walk test, pulmonary function (expressed as % vital capacity [VC]), and MVPA. The results of the final MVPA measurement were excluded from the analysis because they were influenced by the Sports Challenge Program. Additionally, we calculated the reliability coefficients for all items using the intraclass correlation coefficient (ICC) based on the results of the initial and final measurements. Secondary analyses were conducted for variables showing significant correlations with SMI, using SMI as the dependent variable. Age, sex, BMI, and MVPA were considered as potential confounding factors, along with other explanatory variables. Sample size calculations were performed using G*Power 3.1.9.7 (Faul et al., 2009). For the multiple linear regression analysis, we assumed an effect size f^2 of 0.30, a significance level of 5%, a power of 80%, and five explanatory variables, resulting in a required sample size of 49 participants.

Results

The participant selection process is illustrated in Fig. 1. A total of 66 participants attended our sports classes. Seven individuals declined to participate, three had a physical disability (e.g., cerebral palsy), and three were unable to undergo BIA measurements, resulting in a final analyzed sample of 53 participants (21 females). Some participants were unable to remain stationary in a standing position during the BIA measurements, which led to errors in the results. Table 1 gives the characteristics of the participants.

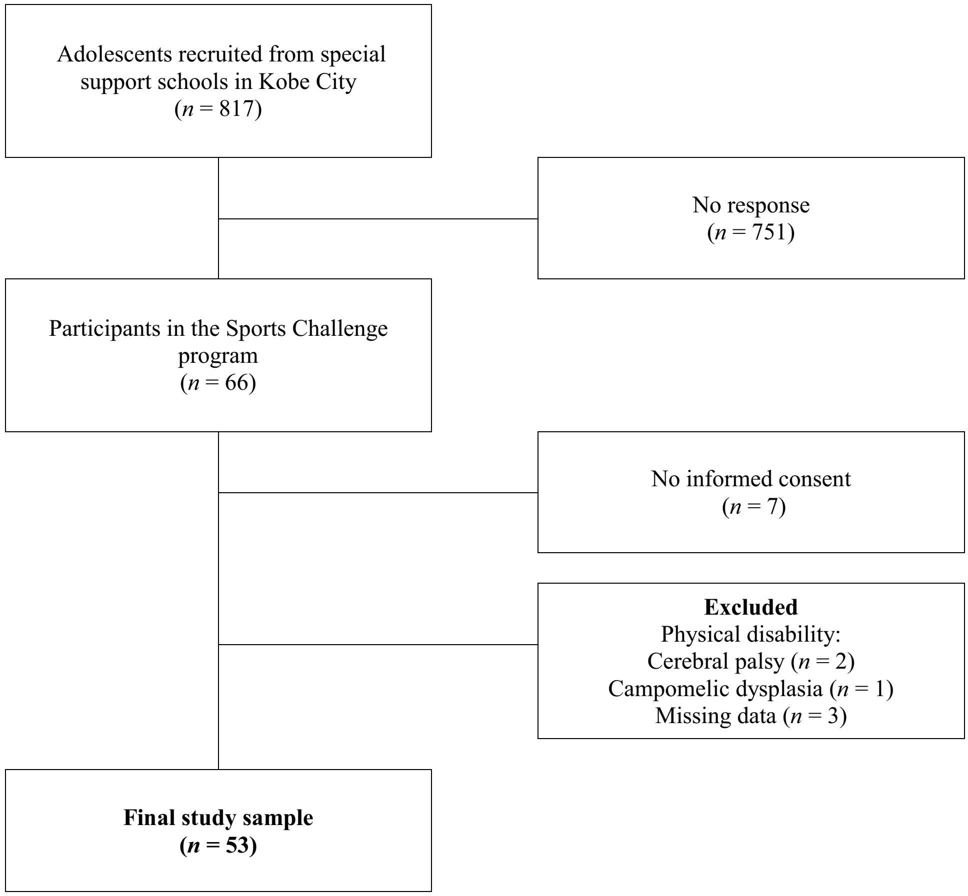

Fig. 1 Study sample selection

Table 1 Characteristics of the participants ($n = 53$)

Age (year), mean (SD) [range]	15.0 (1.7)	[12–18]
Sex (female)	32 (21)	
Height (cm), mean (SD)	159.0 (9.1)	
Weight (kg), mean (SD)	55.7 (10.7)	
BMI (kg/m^2)	21.8 (3.5)	
Overweight, n (%) *	10 (18.9)	
Underweight, n (%) *	9 (17.0)	
Intellectual disability		
Mild (IQ51 to 75)	31	
Moderate (IQ36 to 50)	13	
Severe (less than IQ35)	9	
Diagnoses		
Autism spectrum disorder	16	
Attention-Deficit / Hyperactivity Disorder (ADHD)	6	
Down's syndrome	8	
Prader-Willi syndrome	1	
Rubinstein-Taybi syndrome	1	

n number, *SD* standard deviation, *BMI* body mass index, *IQ* intelligence quotient

*BMI cut-offs for overweight status and underweight status were 25 kg/m^2 and 18.5 kg/m^2

Table 2 shows the physical function measurement results. No outliers were identified in any of the measurements. All measurement items conformed to a normal distribution except for MVPA. Males demonstrated significantly higher values for SMI, handgrip strength, standing long jump, sit-ups, and VC than females.

Table 3 shows the calculation results of the ICC for the initial and four-week follow-up measurements. SMI and BMI, handgrip strength, and standing long jump had ICC estimates of 0.9 or higher; sit-ups, sit-and-reach, VC, and %VC had values between 0.9 and 0.75; the six-minute walk test had values between 0.75 and 0.5. Some participants struggled to hold the mouthpiece correctly during pulmonary function tests, causing air leakage and reducing the test completion rate. Previous studies have reported that an ICC of less than 0.5 is considered poor, 0.5 to 0.75 is moderate, 0.75 to 0.9 is good, and greater than 0.9 is excellent (Koo & Li, 2016).

Table 4 shows the correlations between SMI and each physical fitness measurement (handgrip strength, standing long jump, sit-ups, sit-and-reach, six-minute walk test, %VC, MVPA). We noted significant correlations between SMI and handgrip strength ($r = 0.49$, 95% confidence interval; CI = 0.25–0.67, $p < 0.001$), and between SMI

Table 2 Physical function outcomes of the participants

Measure	Successful completion		Total $n = 53$	Male $n = 32$	Female $n = 21$	*P*-value
Skeletal muscle mass index (kg/ m^2)	53	100%	8.88 (1.16)	9.35 (1.13)	8.18 (0.78)	**< 0.001****
Body mass index (kg/ m^2)	53	100%	22.06 (3.65)	21.27 (3.43)	23.29 (3.80)	0.050
Handgrip strength (kg)	53	100%	22.56 (7.68)	25.17 (8.40)	18.59 (4.07)	**0.002****
Standing long jump (cm)	53	100%	140.15 (41.30)	152.91 (43.35)	120.71 (29.41)	**0.004****
Sit—ups (n)	49	92%	15.71 (5.84)	17.10 (5.67)	13.33 (5.49)	**0.028***
Sit—and—reach (cm)	53	100%	38.49 (13.51)	36.16 (13.27)	42.05 (13.40)	0.122
Six—minute walk (m)	51	96%	476.82 (75.24)	487.22 (80.15)	459.32 (64.40)	0.203
VC (L)	32	60%	3.03 (0.92)	3.35 (1.00)	2.56 (0.51)	**0.013***
%VC	32	60%	87.08 (19.27)	87.58 (21.74)	86.34 (15.82)	0.861
MVPA (per day/ week), median (IQR)	44	83%	3.0 (2.0–5.0)	3.0 (2.0–5.8)	2.5 (2.0–4.0)	0.418

n number, *VC* vital capacity, *MVPA* moderate to vigorous physical activity, *IQR* interquartile range

**Statistically significant ($p < 0.01$), *Statistically significant ($p < 0.05$)

Table 3 Reliability of outcome measure test and retest (4 weeks later)

Measure	Successful completion		Test	Retest	MD	SEM	ICC (1,1)	95%CI
Skeletal muscle mass index (kg/ m^2)	46	87%	8.91 (1.14)	9.02 (1.13)	0.10	0.15	0.98	(0.96–0.99)
Body mass index (kg/ m^2)	48	91%	21.95 (3.78)	22.20 (3.79)	0.25	0.23	0.99	(0.98–0.99)
Handgrip strength (kg)	49	92%	22.58 (7.52)	22.08 (7.79)	0.50	1.67	0.95	(0.92–0.97)
Standing long jump (cm)	48	91%	142.08 (39.50)	143.79 (41.15)	1.71	10.69	0.93	(0.88–0.96)
Sit—ups (n)	45	85%	15.93 (5.47)	16.84 (5.46)	0.91	1.89	0.87	(0.78–0.93)
Sit—and—reach (cm)	49	92%	38.86 (13.43)	37.86 (11.86)	1.00	6.21	0.76	(0.61–0.86)
Six—minute walk (m)	47	89%	478.89 (76.86)	489.57 (85.56)	10.68	48.70	0.64	(0.44–0.78)
VC (L)	27	51%	3.18 (0.81)	3.09 (0.90)	0.09	0.31	0.87	(0.74–0.94)
%VC (%)	27	51%	88.37 (18.85)	91.44 (17.88)	3.07	8.98	0.76	(0.54–0.88)

MD difference between means, *SEM* standard error of measurement, *ICC* intraclass correlation coefficient, *CI* confidence interval, *VC* vital capacity

Table 4 Correlation between the variables

Variable	1	2	3	4	5	6	7	8
1. Skeletal muscle mass index	-							
2. Handgrip strength	**0.49****	-						
3. Standing long jump	**0.39***	**0.73****	-					
4. Sit—ups	0.23	**0.60****	**0.62****	-				
5. Sit—and—reach	0.12	0.07	-0.03	-0.12	-			
6. Six—minute walk	-0.04	0.20	0.25	**0.33***	-0.04	-		
7. %VC	0.22	0.32	0.26	0.24	0.31	0.10	-	
8. MVPA	-0.02	0.05	-0.05	-0.22	-0.11	-0.01	-0.13	-

VC vital capacity, *MVPA* moderate to vigorous physical activity

**Statistically significant ($p < 0.01$), *Statistically significant ($p < 0.05$)

and standing long jump (r = 0.39, 95% CI = 0.13–0.59, p = 0.004). However, we found no significant association between SMI and sit-ups, sit-and-reach, the six-minute walk test, %VC, or MVPA. Significant correlations were observed between handgrip strength and standing long jump (r = 0.73, 95% CI = 0.56–0.83, $p < 0.001$).

We conducted a secondary analysis using multiple linear regression with SMI as the dependent variable and handgrip strength and standing long jump as independent variables, controlling for potential confounders: age, sex, BMI, and MVPA (Table 5). We identified a significant positive regression coefficient in Model. 1, focusing on handgrip strength (standardized regression coefficient: B = 0.44, 95% CI = 0.23–0.65, $p < 0.001$, adjusted $R^2 = 0.71$). Each variable's variance inflation factor (VIF) was less than 10, indicating no multicollinearity. Similarly, Model. 2 analyzed standing long jump (B = 0.44, 95% CI = 0.25–0.62, $p < 0.001$, adjusted $R^2 = 0.73$), again showing a significant positive regression coefficient with no multicollinearity (VIF < 10). The normality of the residuals was confirmed by checking the Normal Q-Q plots in both models.

Discussion

We observed that, even after accounting for confounding factors such as age, sex, BMI, and MVPA, a significant association persisted between SMI and both handgrip strength and standing long jump performance. This finding further elucidates the relationship between SMI and physical function in adolescents with IDD. Handgrip strength and standing long jump could potentially serve as effective indicators for evaluating the development of limb skeletal muscles in adolescents with IDD.

Table 5 Multiple linear regression results for the association of skeletal muscle mass index (SMI) and predictors

	B (95%CI)	SE B	β	P-value
Model. 1				
Adjusted R^2			**0.71**	
Intercept	-0.63 (-0.92– -0.34)	0.14		
Age	0.17 (0.00–0.34)	0.08	0.11	**0.046***
Sex	0.96 (0.55–1.37)	0.20	1.11	**< 0.001****
BMI	0.59 (0.41–0.77)	0.09	0.19	**< 0.001****
Handgrip strength	0.44 (0.23–0.65)	0.10	0.07	**< 0.001****
MVPA	-0.15 (-0.32–0.02)	0.08	-0.08	0.090
Model. 2				
Adjusted R^2			**0.73**	
Intercept	-0.68 (-0.95– -0.41)	0.13		
Age	0.20 (0.04–0.36)	0.08	0.13	**0.018***
Sex	1.06 (0.68–1.43)	0.18	1.21	**< 0.001****
BMI	0.71 (0.53–0.89)	0.09	0.23	**< 0.001****
Standing long jump	0.44 (0.25–0.62)	0.09	0.01	**< 0.001****
MVPA	-0.09 (-0.26–0.08)	0.08	-0.05	0.270

Model 1; Multiple linear regression analyses revealed that age, sex, BMI, hand grip strength and MVPA were associated with SMI

Model 2; Multiple linear regression analyses revealed that age, sex, BMI, standing long jump and MVPA were associated with SMI

CI confidence interval, *SE* standard error, *BMI* body mass index, *MVPA* moderate to vigorous physical activity

**Statistically significant ($p < 0.01$), *Statistically significant ($p < 0.05$)

The association between skeletal muscle mass and handgrip strength, a simple and practical measure for tracking changes in children's health status, has been observed even in healthy adolescents (Zembura et al., 2023; Peterson et al., 2018). Handgrip strength, which reflects overall muscle strength, is included in the diagnostic criteria for sarcopenia in adults (Chen et al., 2020; Sayer et al., 2008). Standing long jump requires overall coordination and balance, and, more specifically, lower limb muscle strength. The association between SMI and standing long jump may be attributed to muscle mass in the lower limbs. All participants capable of SMI measurement were also able to perform a standing long jump. Compared to the equipment and effort involved in SMI measurement, performing a standing long jump is relatively straightforward. However, considering factors such as the risk of falls, handgrip strength measurement is regarded as a more practical evaluation method. No significant association with SMI was observed for sit-ups or the sit-and-reach test. Studies have reported the association of SMI with pulmonary function and respiratory muscle strength in healthy youths (Sawaya et al., 2018). However, we did not find a significant association with pulmonary function. Despite adequate training and multiple measurements, only 32 of 53 participants (60%) were able to complete the pulmonary function tests properly. The difficulties in performing pulmonary function tests in individuals with IDD have been reported (Vielkind et al., 2022). Further investigation is needed regarding their validity among adolescents with IDD.

Limb skeletal muscle mass in healthy children is associated with physical activity levels, which are suggested to be related to bodily functions such as handgrip strength, walking efficiency, TUG, and one-legged standing (Ito et al., 2021). In healthy adolescents, the association between the six-minute walk test and SMI has been reported (Zembura et al., 2023). Previous studies have shown the reliability and validity of the six-minute walk test in adolescents with IDD (Elmahgoub et al., 2012). However, we observed no association between SMI and a six-minute walk distance. The six-minute walk test necessitates an understanding of pacing and strategy, which may be affected by cognitive function. As an indicator reflecting the SMI of individuals with IDD included in this study, its applicability may differ from that observed in healthy individuals.

Regarding physical activity levels, we identified no significant factors affecting SMI in our sample. Adolescence is a crucial period for developing skeletal muscles, and the role of physical activity and sports during this stage is essential (Scifo et al., 2019). Habitual physical activity and high-frequency MVPA reportedly lead to increased limb skeletal muscle mass. Nevertheless, clear conclusions have not been reached regarding the level of physical activity necessary for this increase. While physical activity during adolescence can positively affect lean body mass increase (Baxter-Jones et al., 2008), studies investigating healthy adolescents have reported no association between non-fat mass (skeletal muscle mass) and physical activity levels (Moliner-Urdiales et al., 2010). The development of skeletal muscles during growth may involve various confounding factors, such as type of physical activity, nutritional status, genetic factors, and socio-economic status.

This study has several limitations. First, the findings are based on students who expressed interest in participating in sports classes. As a result, the outcomes may not accurately reflect the general physical characteristics or athletic abilities of students attending special education schools in the region. Furthermore, over half of the participants were adolescents with relatively high intellectual abilities; therefore, future studies should include a greater number of individuals with severe intellectual disabilities. Physical activity levels in this study were assessed through interviews; however, reliable responses were unavailable for 9 out of the 53 participants. Subjective evaluations, such as interviews, are prone to overestimating physical activity levels compared to objective measures, such as accelerometers (Ekelund et al., 2011). Recall bias may have also affected the results. Furthermore, only 4 out of 53 participants reported meeting the recommended daily minimum of one hour of MVPA (Bull et al., 2020). Participants who regularly engaged in high-intensity physical activities were likely underrepresented in the finding. Owing to the program schedule, the re-test to confirm reproducibility was conducted four weeks later. Although the sports program intervention was conducted only four times during this period, which likely minimized its impact, conducting the re-test over a shorter period would have been necessary to verify reproducibility more effectively.

Conclusions

This study revealed significant associations between skeletal muscle mass index and physical fitness indicators, such as handgrip strength and standing long jump, in adolescents with intellectual and developmental disabilities. These measures may be effective indicators for assessing limb skeletal muscle development in this population. Conversely, no significant associations were identified between skeletal muscle mass and sit-ups, sit-and-reach test, six-minute walk test, pulmonary function tests, or physical activity levels. This study suggests that handgrip strength, which is easier to measure than the standing long jump and also highly reliable, could serve as a practical screening tool for obesity-related sarcopenia in adolescents with intellectual and developmental disabilities. Based on the finding of this research, it is crucial for healthcare providers, educators, and policymakers to collaborate in designing and implementing tailored physical activity that enhance physical health outcomes among adolescents with intellectual and developmental disabilities.

Acknowledgements The authors are grateful to the participants and their families who contributed to this study and to the volunteer staff who assisted with the measurements.

Funding Open Access funding provided by Kobe University. This work was supported by JSPS KAKENHI Grant Number JP23K19924, the Japan Sports Agency's 2022 Disability Sports Promotion Project Budget (Disability Sports Provision System Development Project), and the 2023 budget for community collaboration at the Graduate School of Health Sciences, Kobe University.

Data Availability The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available because of privacy and ethical restrictions.

Declarations

Ethics approval This study was conducted in accordance with the Helsinki Declaration and obtained approval from the Ethics Committee of the Graduate School of Health Sciences, Kobe University (No. 1136–1). Participants who obtained written consent from their guardians were included. Additionally, research information was made publicly available on the website of the Graduate School of Health Sciences, Kobe University, and opportunities for consent withdrawal were ensured.

Conflict of Interest The authors declare no conflict of interest.

References

Andersen, L. B., Sardinha, L. B., Froberg, K., Riddoch, C. J., Page, A. S., & Anderssen, S. A. (2008). Fitness, fatness and clustering of cardiovascular risk factors in children from Denmark, Estonia and Portugal: The European Youth Heart Study. *International Journal of Pediatric Obesity, 3*(Suppl 1), 58–66. https://doi.org/10.1080/17477160801896366

ATS statement: guidelines for the six-minute walk test. (2002). *American Journal of Respiratory and Critical Care Medicine, 166*(1), 111-117.https://doi.org/10.1164/ajrccm.166.1.at1102

Baxter-Jones, A. D., Eisenmann, J. C., Mirwald, R. L., Faulkner, R. A., & Bailey, D. A. (2008). The influence of physical activity on lean mass accrual during adolescence: a longitudinal analysis. *Journal of Applied Physiology (1985), 105*(2), 734–741. https://doi.org/10.1152/japplphysiol.00869.2007

Bull, F. C., Al-Ansari, S. S., Biddle, S., Borodulin, K., Buman, M. P., Cardon, G., Carty, C., Chaput, J. P., Chastin, S., Chou, R., Dempsey, P. C., DiPietro, L., Ekelund, U., Firth, J., Friedenreich, C. M., Garcia, L., Gichu, M., Jago, R., Katzmarzyk, P. T., … Willumsen, J. F. (2020). World Health Organization 2020 guidelines on physical activity and sedentary behaviour. *British Journal of Sports Medicine, 54*(24), 1451–1462. https://doi.org/10.1136/bjsports-2020-102955

Chen, L. K., Woo, J., Assantachai, P., Auyeung, T. W., Chou, M. Y., Iijima, K., Jang, H. C., Kang, L., Kim, M., Kim, S., Kojima, T., Kuzuya, M., Lee, J. S. W., Lee, S. Y., Lee, W. J., Lee, Y., Liang, C. K., Lim, J. Y., Lim, W. S., … Arai, H. (2020). Asian Working group for Sarcopenia: 2019 Consensus update on sarcopenia diagnosis and treatment. *Journal of the American Medical Directors Association, 21*(3), 300-307.e302.https://doi.org/10.1016/j.jamda.2019.12.012

Dent, E., Morley, J. E., Cruz-Jentoft, A. J., Arai, H., Kritchevsky, S. B., Guralnik, J., Bauer, J. M., Pahor, M., Clark, B. C., Cesari, M., Ruiz, J., Sieber, C. C., Aubertin-Leheudre, M., Waters, D. L., Visvanathan, R., Landi, F., Villareal, D. T., Fielding, R., Won, C. W., Theou, O., …Vellas, B. (2018). International Clinical Practice Guidelines for Sarcopenia (ICFSR): Screening, diagnosis and management. *The Journal of Nutrition, Health & Aging, 22*(10), 1148–1161. https://doi.org/10.1007/s12603-018-1139-9

Ekelund, U., Tomkinson, G., & Armstrong, N. (2011). What proportion of youth are physically active? Measurement issues, levels and recent time trends. *British Journal of Sports Medicine, 45*(11), 859–865. https://doi.org/10.1136/bjsports-2011-090190

Elmahgoub, S. S., Van de Velde, A., Peersman, W., Cambier, D., & Calders, P. (2012). Reproducibility, validity and predictors of six-minute walk test in overweight and obese adolescents with intellectual disability. *Disability and Rehabilitation, 34*(10), 846–851. https://doi.org/10.3109/09638288.2011.623757

Faul, F., Erdfelder, E., Buchner, A., & Lang, A. G. (2009). Statistical power analyses using G*Power 3.1: tests for correlation and regression analyses. *Behavior Research Methods, 41*(4), 1149–1160. https://doi.org/10.3758/brm.41.4.1149

Golubović, Š, Maksimović, J., Golubović, B., & Glumbić, N. (2012). Effects of exercise on physical fitness in children with intellectual disability. *Research in Developmental Disabilities, 33*(2), 608–614. https://doi.org/10.1016/j.ridd.2011.11.003

Graham, B. L., Steenbruggen, I., Miller, M. R., Barjaktarevic, I. Z., Cooper, B. G., Hall, G. L., Hallstrand, T. S., Kaminsky, D. A., McCarthy, K., McCormack, M. C., Oropez, C. E., Rosenfeld, M., Stanojevic, S., Swanney, M. P., & Thompson, B. R. (2019). Standardization of spirometry 2019 Update. An official American thoracic society and European respiratory society technical statement. *American Journal of Respiratory and Critical Care Medicine, 200*(8), e70–e88. https://doi.org/10.1164/rccm.201908-1590ST

Hartman, E., Smith, J., Westendorp, M., & Visscher, C. (2015). Development of physical fitness in children with intellectual disabilities. *Journal of Intellectual Disability Research, 59*(5), 439–449. https://doi.org/10.1111/jir.12142

Hurtig-Wennlöf, A., Ruiz, J. R., Harro, M., & Sjöström, M. (2007). Cardiorespiratory fitness relates more strongly than physical activity to cardiovascular disease risk factors in healthy children and adolescents: the European Youth Heart Study. *European Journal of Cardiovascular Prevention and Rehabilitation, 14*(4), 575–581. https://doi.org/10.1097/HJR.0b013e32808c67e3

Ito, T., Sugiura, H., Ito, Y., Noritake, K., & Ochi, N. (2021). Relationship between the skeletal muscle mass index and physical activity of Japanese children: A cross-sectional, observational study. *PLoS ONE, 16*(5), e0251025. https://doi.org/10.1371/journal.pone.0251025

Janssen, I., Heymsfield, S. B., & Ross, R. (2002). Low relative skeletal muscle mass (sarcopenia) in older persons is associated with functional impairment and physical disability. *Journal of the American Geriatrics Society, 50*(5), 889–896. https://doi.org/10.1046/j.1532-5415.2002.50216.x

Kanda, Y. (2013). Investigation of the freely available easy-to-use software 'EZR' for medical statistics. *Bone Marrow Transplantation, 48*(3), 452–458. https://doi.org/10.1038/bmt.2012.244

Kim, K. M., & Lee, C. E. (2023). Promoting Physical Activity Participation Among People with Intellectual and Developmental Disabilities in South Korea. *Journal of Developmental and Physical Disabilities, 35*(3), 473–486. https://doi.org/10.1007/s10882-022-09861-w

Kim, K., Hong, S., & Kim, E. Y. (2016). Reference values of skeletal muscle mass for Korean children and adolescents using data from the Korean National health and nutrition examination survey 2009–2011. *PLoS ONE, 11*(4), e0153383. https://doi.org/10.1371/journal.pone.0153383

Koo, T. K., & Li, M. Y. (2016). A Guideline of Selecting and Reporting Intraclass Correlation Coefficients for Reliability Research. *Journal of Chiropractic Medicine, 15*(2), 155–163. https://doi.org/10.1016/j.jcm.2016.02.012

Moliner-Urdiales, D., Ortega, F. B., Vicente-Rodriguez, G., Rey-Lopez, J. P., Gracia-Marco, L., Widhalm, K., Sjöström, M., Moreno, L. A., Castillo, M. J., & Ruiz, J. R. (2010). Association of physical activity with muscular strength and fat-free mass in adolescents: the HELENA study. *European Journal of Applied Physiology, 109*(6), 1119–1127. https://doi.org/10.1007/s00421-010-1457-z

Morley, J. E., Baumgartner, R. N., Roubenoff, R., Mayer, J., & Nair, K. S. (2001). Sarcopenia. *Journal of Laboratory and Clinical Medicine, 137*(4), 231–243. https://doi.org/10.1067/mlc.2001.113504

Oeseburg, B., Dijkstra, G. J., Groothoff, J. W., Reijneveld, S. A., & Jansen, D. E. (2011). Prevalence of chronic health conditions in children with intellectual disability: a systematic literature review. *Intellectual and Developmental Disabilities, 49*(2), 59–85. https://doi.org/10.1352/1934-9556-49.2.59

Peterson, M. D., Gordon, P. M., Smeding, S., & Visich, P. (2018). Grip strength is associated with longitudinal health maintenance and improvement in adolescents. *Journal of Pediatrics, 202*, 226–230. https://doi.org/10.1016/j.jpeds.2018.07.020

Salaun, L., & Berthouze-Aranda, S. E. (2012). Physical fitness and fatness in adolescents with intellectual disabilities. *Journal of Applied Research in Intellectual Disabilities, 25*(3), 231–239. https://doi.org/10.1111/j.1468-3148.2012.00659.x

Sawaya, Y., Ishizaka, M., Kubo, A., Sadakiyo, K., Yakabi, A., Sato, T., Shiba, T., Onoda, K., & Maruyama, H. (2018). Correlation between skeletal muscle mass index and parameters of respiratory function and muscle strength in young healthy adults according to gender. *Journal of Physical Therapy Science, 30*(12), 1424–1427. https://doi.org/10.1589/jpts.30.1424

Sayer, A. A., Syddall, H., Martin, H., Patel, H., Baylis, D., & Cooper, C. (2008). The developmental origins of sarcopenia. *Journal of Nutrition, Health and Aging, 12*(7), 427–432. https://doi.org/10.1007/bf02982703

Scifo, L., Chicau Borrego, C., Monteiro, D., Matosic, D., Feka, K., Bianco, A., & Alesi, M. (2019). Sport Intervention Programs (SIPs) to Improve Health and Social Inclusion in People with Intellectual Disabilities: A Systematic Review. *Journal of Functional Morphology and Kinesiology, 4*(3), 57. https://doi.org/10.3390/jfmk4030057

Sung, W. J., Kim, W. J., Hwang, Y., Kim, J. S., Lim, S. H., & Hong, B. Y. (2020). Body composition of school-aged children with disabilities. *Pediatrics International, 62*(8), 962–969. https://doi.org/10.1111/ped.14248

Tabata, H., Otsuka, H., Shi, H., Sugimoto, M., Kaga, H., Someya, Y., Naito, H., Ito, N., Abudurezake, A., Umemura, F., Kiya, M., Tajima, T., Kakehi, S., Yoshizawa, Y., Kawamori, R., Watada, H., & Tamura, Y. (2023). Effects of exercise habits in adolescence and older age on sarcopenia risk in older adults: the Bunkyo Health Study. *Journal of Cachexia, Sarcopenia and Muscle, 14*(3), 1299–1311. https://doi.org/10.1002/jcsm.13218

Tanaka, C., Kyan, A., Takakura, M., Olds, T., Schranz, N., Tanaka, M., & Tanaka, S. (2017). The validity of the Japanese version of physical activity questions in the WHO Health Behaviour in School-aged Children (HBSC) survey. *Research in Exercise Epidemiology, 19*(2), 93–101. https://doi.org/10.24804/ree.19.93

Vielkind, M. L., Hamlington, K. L., Wolter-Warmerdam, K., Meier, M. R., Liu, A. H., Hickey, F. J., Brown, M. A., & DeBoer, E. M. (2022). Airwave oscillometry to measure lung function in children with Down syndrome. *Pediatric Research, 91*(7), 1775–1780. https://doi.org/10.1038/s41390-021-01664-7

Wouters, M., Evenhuis, H. M., & Hilgenkamp, T. I. (2017). Systematic review of field-based physical fitness tests for children and adolescents with intellectual disabilities. *Research in Developmental Disabilities, 61*, 77–94. https://doi.org/10.1016/j.ridd.2016.12.016

Wouters, M., Evenhuis, H. M., & Hilgenkamp, T. I. M. (2020). Physical fitness of children and adolescents with moderate to severe intellectual disabilities. *Disability and Rehabilitation, 42*(18), 2542–2552. https://doi.org/10.1080/09638288.2019.1573932

Zembura, M., & Matusik, P. (2022). Sarcopenic obesity in children and adolescents: a systematic review [Systematic Review]. *Frontiers in Endocrinology, 13*, 914740. https://doi.org/10.3389/fendo.2022.914740

Zembura, M., Czepczor-Bernat, K., Dolibog, P., Dolibog, P. T., & Matusik, P. (2023). Skeletal muscle mass, muscle strength, and physical performance in children and adolescents with obesity. *Front Endocrinol (Lausanne), 14*, 1252853. https://doi.org/10.3389/fendo.2023.1252853