

Association between Toe Grip Strength and Physical Performance Among Japanese Preschool Children

Daisuke Uritani^{1*}, Takahiko Fukumoto¹, Daisuke Matsumoto¹ and Masayuki Shima²

¹Department of Physical Therapy, Faculty of Health Science, Kio University, Nara, Japan

²Department of Public Health, Hyogo College of Medicine, Nishinomiya, Hyogo, Japan

Corresponding Author: Daisuke Uritani, Department of Physical Therapy, Kio University, Japan; Tel: +81-745-54-1601; Fax: +81-745-1600; E-mail: d.uritani@kio.ac.jp

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Abstract

Objective: To evaluate the association between Toe grip strength (TGS) and physical performance among preschool children in Japan.

Methods: TGS was evaluated in 338 preschool children (178 boys, 160 girls), 4–6 years of age. The following physical performance tests were measured: hand grip strength (HGS), 25-m sprint run, 5-m shuttle run, standing long jump, and tennis ball throw, were measured. Participants were divided into five age groups of 6-month intervals, from the early 4-years-old group (48-53 months) to the early 6-years-old group (72-78 months). TGS was analyzed using a two-way analysis of variance, with a post-hoc test to assess between-sex differences and age-related changes. Associations between TGS and descriptive characteristics and physical performance were assessed using multivariate linear regression analysis.

Results: TGS increased with development, being significantly greater in the early 6-years-old group than in the early and late 4-years-old group and early 5-years-old group. There was no between-sex difference in TGS within the same age group. TGS was associated with age in months and weight, but not with sex and height. TGS was also significantly associated with the 25-m sprint run, 5-m shuttle run and standing long jump performance, regardless of age, anthropometrics and HGS, in both sex, with the exception of the 5-m shuttle run in boys.

Conclusion: TGS increased with age and was associated with enhanced lower-limb physical performance among preschool children and could provide a useful predictor of physical performance in this population.

Keywords: Toes; Muscle; Strength; Physical performance; Fitness; Children; Preschooler

Introduction

Toe function influences physical performance among adults [1-4], with toe flexor strength decreasing with aging [1,5,6]. However, although toe flexor strength has been reported in various studies, it has not been measured using a standardized method, such as hand grip strength (HGS). To address this issue, we previously developed a toe grip dynamometer [7] and established reference values of toe grip strength (TGS) for adults 20 to 79 years old [8]. We also reported relevant factors that influence TGS in adults [8,9]. The utility of TGS as an index of physical performance, however, as not been clearly evaluated in children.

Recently, Morita et al. [10] reported TGS values for elementary school children in the third and fifth grade. However, TGS values of preschool children are still unknown, although several studies have focused on foot characteristics in this population [10-13]. Some studies have reported that all children are born with flatfeet, with normal foot posture, including a longitudinal arch, develops over the first decade of life [14,15]. Thus, it is believed that foot and toe function may change with age over this time period, and that TGS may also change remarkably during preschool. In addition, establishing normative data

of TGS among preschool children may provide useful fundamental data for similar research in the future.

Several researchers have reported associations between toe function, including toe flexor strength, and balance [1,4] and walking [2,3] in adults, as previously mentioned. Various reports have also indicated that reduced toe flexor strength is an important risk factor for falls among elderly individuals [16-18]. Thus, it can be assumed that toe function is associated with physical performance in adults. In elementary school children, Morita et al. [10] reported that relative TGS (TGS/body mass) significantly correlated with the 50 m sprint run, standing long jump, repeated side step, and rebound jump. However, this association between TGS and physical performance has not been evaluated in other studies, and has not been evaluated in preschool children. Hence, clarifying the relationship between TGS and physical performance may reveal the importance of TGS development in this population. Therefore, the purpose of our study was to evaluate TGS and evaluate its association with physical performance in preschool children. We hypothesized that TGS development would be significantly associated to physical performance among preschool children.

Participants and Methods

We enrolled 339 preschool children from Kashihara City, Nara Prefecture, Japan. One girl was excluded from the study because she

could not perform all the tests without the assistance from a teacher. Therefore, 338 preschool children (178 boys, 160 girls), 4 to 6 years old (mean 4.7 ± 0.6 years) were included. The children came from two daycare centers (n=187, 55.3%) and two kindergarten classes (n=151, 44.7%).

This study was approved by the Kio university research ethics committee (H23-36, H25-3) and conformed to the tenets of the Declaration of Helsinki. Details of the testing procedures and the aim of the study were explained, and written informed consent obtained from each owner/principal of the daycare centers and kindergarten classes. Teachers and pediatric nurses from participating facilities provided the details and aims of our study to the participant's parents and/or guardians, and written informed consent was also obtained from all of the participant's parents and/or guardians, with assent obtained from the children.

Morphological data were obtained from participants annual health check-up, held in April and May, 2012. Height and weight were measured while participants wore lightweight clothing and were bare footed.

The following measures of physical performance were obtained: HGS, 25-m sprint run, 5-m shuttle run, standing long jump, and tennis ball throw. These measures are typically used to measure the physical performance of children in Japan. All physical performance tests were performed in a random order.

TGS was measured using the toe grip dynamometer (TKK 3362, Takei Scientific Instruments, Niigata, Japan), using the procedures described by Uritani et al. [7]. Since muscle strength of the first toe has been reported to have the strongest association with TGS among all the toes [19], the first toe was used as a benchmark to set-up the testing position. Two measures of TGS were obtained on each side. The best value of TGS was recorded on each side. HGS was measured using a hand grip dynamometer for children (TKK 5825, Takei Scientific Instruments). Children were instructed to stand in a relaxed position, face forward with their arms hanging at the side of their body, and then to apply maximum pressure for approximately 3 seconds. The HGS was measured twice on each side. The best value of HGS was recorded on each side. The 25-m sprint run was measured using a stopwatch. Participants were instructed to run from a standing position. After the signal was given, they sprinted for 25-m on a dirt track as fast as possible. The 5-m shuttle run was also measured using a stopwatch. Children were instructed to run four 5-m laps as fast as possible. The standing long jump was measured between the start line

and the landing point on the ground using a tape measure. Children were instructed to jump horizontally as far as possible using both legs; arm swing was permitted. The tennis ball throw was also measured using a tape measure. Children were instructed to throw a tennis ball, approximately 6.5 cm in diameter and weighing approximately 60 g, with an overhand throw as far as possible. The 25-m sprint run, the standing long jump, and the tennis ball throw were performed twice. For analysis, the mean of the two measurements for all outcome variables was used. Mean TGS and HGS were calculated using the best score on each side.

Participants were divided into five age groups, in 6 month intervals as per the criteria described by Robertson and Deitz [20]. Age in months was calculated from the date of birth. The five age groups used for analysis were defined as follows: Early 4-years-old group, 49 to 54 months; late 4-years-old group, 55 to 60 months; early 5-years-old group, 61 to 66 months; late 5-years-old group, 67 to 72 months; and early 6-years-old group, 73 to 78 months. No participants were included in the late 6 year old group because the academic year starts in April in Japan, and our study was conducted in April and May.

The reproducibility of the TGS measurements was evaluated by calculating the within observer intra class correlation coefficient (ICC), model (1,2). TGS was analyzed using a two-way analysis of variance (ANOVA), with Tukey's post-hoc test used to assess between-sex differences and age-related changes. To determine the association between TGS and descriptive characteristics (age in months, sex, height, and weight), multivariate linear regression analysis, using a forced entry method, was performed. In addition, Pearson's correlation coefficients and multivariate linear regression analyzes, again using a forced entry method, were performed to evaluate the association between TGS and physical performance tests. The multivariate linear regression analysis was performed by sex, because between sex differences were observed in the results of physical performance tests based on the preliminary analysis. In the multivariate linear regression analysis, independent variables were outcomes of each of the physical performance tests, and the dependent variables were age in months, height, weight, HGS, and TGS. The two tailed significance level was set at 5%. All data were analyzed using IBM SPSS (version, 22.0; IBM Japan, Tokyo, Japan).

Results

Participants demographics and physical performance test outcomes are reported by age groups (Table 1).

	Boys						Girls					
	Early 4 yo	Late 4 YO	Early 5 yo	Late 5 YO	Early 6 yo	Total	Early 4 yo	Late 4 yo	Early 5 yo	Late 5 YO	Early 6 yo	Total
Height (cm)	102.6 (4.9)	105.7 (4.2)	108.3 (5.1)	109.7 (4.3)	114.3 (5.6)	107.3 (5.7)	101.8 (4.1)	103.9 (4.1)	107.5 (4.4)	110.1 (4.2)	114.4 (4.1)	107.0 (5.6)
Weight (kg)	16.3 (1.9)	17.5 (2.2)	18.0 (2.1)	18.2 (2.0)	20.6 (2.4)	17.8 (2.3)	16.0 (1.7)	16.9 (2.1)	17.6 (2.4)	18.4 (1.6)	21.0 (3.7)	17.7 (2.6)
HGS (kg)	5.1 (1.5)	6.0 (1.6)	6.6 (1.7)	7.1 (1.8)	8.8 (1.5)	6.4 (1.9)	4.8 (1.3)	5.2 (1.4)	6.4 (1.5)	6.8 (1.9)	8.2 (2.1)	6.1 (1.9)
25- m run	7.6	7.1	6.6	6.4	6.1	6.8	7.6	7.5	7.0	6.4	6.3	7.0

(s)	(0.7)	(0.8)	(0.7)	(0.5)	(0.3)	(0.8)	(0.8)	(0.8)	(0.7)	(0.4)	(0.6)	(0.8)
5-m shuttle (s)	25.2 (2.8)	23.5 (2.3)	21.3 (2.0)	21.1 (1.7)	20.3 (1.2)	22.5 (2.7)	25.6 (2.9)	24.3 (2.8)	22.6 (2.3)	21.5 (1.6)	21.5 (1.8)	23.1 (2.7)
Long jump (cm)	85.8 (17.0)	89.3 (18.2)	99.6 (13.7)	105.0 (15.3)	110.1 (21.2)	96.5 (18.5)	79.6 (20.6)	81.5 (16.5)	88.7 (14.3)	97.3 (12.7)	104.2 (17.0)	89.0 (17.6)
Ball throw (m)	5.7 (1.8)	6.8 (2.2)	8.4 (2.5)	8.2 (2)	9.8 (4.1)	7.5 (2.6)	4.7 (1.3)	5.5 (1.7)	5.7 (1.7)	6.5 (1.7)	7.0 (1.6)	5.8 (1.7)

yo: Years old; Early 4 yo: 48–53 months; Late 4 yo: 54–59 months; Early 5 yo: 60–65 months; Late 5 yo: 66–71 months; Early 6 yo: 72–78 months.
HGS: Hand grip strength; 25-m run: 25-m sprint run; 5-m shuttle: 5-m shuttle run; Long jump: Standing long jump; Ball throw: Tennis ball throw.

Table 1: Participants demographic characteristics and physical performance test outcomes (mean standard deviation).

The reliability in TGS measurement was high, with an ICC (1,2) of 0.902 (95% confidence interval [CI], 0.879 to 0.921), based on the criterion of Landis and Koch [21]. A main effect of age (F [4.328]=13.95, p<0.01), but not for sex (F [1.328]=1.92), on TGS was identified, with no significant age × sex interaction (F [4.328]=1.42). The effects of age on TGS are reported in Table 2, with significant effects as follows. TGS was significantly greater in the early 6-years-old

group (6.3 ± 1.8 kg) than in the early 4-years-old (4.0 ± 1.2 kg), late 4-years-old (4.7 ± 1.4 kg) and early 5-years-old (5.1 ± 1.9 kg) groups (p<0.05). TGS was also significantly greater in the late 5-years-old group (5.7 ± 1.8 kg) than in the early and late 4-years-old groups (p<0.05). TGS was also greater in the late 4-years-old and early 5 year old groups than in the early 4-years-old group (p<0.05).

Groups	Boys	Girls	Total
Early 4 yo group	3.8 (1.2)	4.2 (1.3)	4.0 (1.2)
Late 4 yo group	5.0 (1.6)	4.5 (1.2)	4.7 (1.4)a
Early 5 yo group	5.3 (1.7)	5.0 (2.0)	5.1 (1.9)a
Late 5 yo group	5.7 (2.0)	5.7 (1.7)	5.7 (1.8)a,b
Early 6 yo group	6.8 (1.9)	5.8 (1.5)	6.3 (1.8)a,b,c

†Data are expressed as the group mean (Standard deviation).
yo: Years old; TGS: Toe Grip Strength; Early 4 yo: 48–53 Months; late 4 yo: 54–59 months; Early 5 yo: 60–65 months; Late 5 yo: 66–71 months; Early 6 yo: 72–78 months.
a,b,c: p<0.05 versus early 4 yo, late 4 yo and early 5 yo groups respectively.

Table 2: Toe grip strength values for preschool children (mean standard deviation).

On linear regression analysis (Table 3), TGS was significantly associated with age (months) (standardized partial regression

coefficient; β=0.20, p<0.01) and weight (β=0.37, p<0.01), but not with sex and height (adjusted R²=0.30).

	Regression coefficient	SE	β	p value	Adjusted R ²
Intercept	-5.09	1.92	-	<0.01	0.30
Age, months	0.05	0.02	0.20	<0.01	-
Sex	-0.16	0.16	-0.05	0.33	-
Height, cm	0.02	0.03	0.07	0.39	-
Weight, Kg	0.27	0.05	0.37	<0.01	-

SE: Standard error; β: Standardized partial regression coefficient; TGS: Toe grip strength

Table 3: Association between toe grip strength and participants descriptive characteristics.

Results of the linear regression analysis between TGS and the physical performance measures are summarized in Tables 4 and 5. All physical performance tests (25-m sprint run, 5-m shuttle run, standing long jump, and tennis ball throw) were correlated to age in months, height, weight, HGS, and TGS for both sex ($p < 0.01$ for all parameters). When adjusting for age in months, height, weight, and HGS, TGS was significantly associated with the 25-m sprint run in both sex (boys, $\beta = -0.32$, $p < 0.01$, adjusted $R^2 = 0.49$; girls, $\beta = -0.20$, $p < 0.01$, adjusted

$R^2 = 0.45$), 5-m shuttle run in girls ($\beta = -0.18$, $p = 0.02$, adjusted $R^2 = 0.36$) and standing long jump in both sex (boys, $\beta = 0.27$, $p < 0.01$, adjusted $R^2 = 0.35$; girls, $\beta = 0.32$, $p < 0.01$, adjusted $R^2 = 0.38$), but not correlate with the 5-m shuttle run in boys ($\beta = -0.12$, $p = 0.11$, adjusted $R^2 = 0.47$). TGS was not associated with the tennis ball throw, in either sex (boys; $\beta = 0.13$, $p = 0.15$, adjusted $R^2 = 0.26$, girls; $\beta = 0.09$, $p = 0.30$, adjusted $R^2 = 0.26$).

Physical performance		Regression coefficient	SE	β	p value	Adjusted R^2
25-m sprint run	Intercept	10.73	1.06		<0.01	0.49
	Age, months	-0.54	0.09	-0.40	<0.01	
	Height, cm	-0.01	0.010	-0.07	0.48	
	Weight, kg	0.07	0.03	0.21	0.02	
	HGS, kg	-0.10	0.03	-0.24	<0.01	
	TGS, kg	-0.14	0.03	-0.32	<0.01	
5-m shuttle run	Intercept	33.29	3.66		<0.01	0.47
	Age, months	-2.09	0.32	-0.47	<0.01	
	Height, cm	0.00	0.05	0.00	0.98	
	Weight, kg	0.22	0.11	0.19	0.05	
	HGS, kg	-0.49	0.12	-0.34	<0.01	
	TGS, kg	-0.17	0.11	-0.12	0.11	
Standing long jump	Intercept	61.85	27.80		0.03	0.35
	Age, months	8.30	2.43	0.27	<0.01	
	Height, cm	-0.39	0.37	-0.12	0.29	
	Weight, kg	0.26	0.84	0.03	0.76	
	HGS, kg	2.47	0.87	0.25	0.01	
	TGS, kg	2.74	0.82	0.27	<0.01	
Tennis ball throw	Intercept	-0.23	4.12		0.96	0.26
	Age, months	1.17	0.36	0.27	<0.01	
	Height, cm	0.00	0.06	-0.01	0.97	
	Weight, kg	-0.10	0.13	-0.09	0.44	
	HGS, kg	0.43	0.13	0.31	<0.01	
	- TGS, kg	0.18	0.12	0.13	0.15	

SE: Standard error; β : Standardized partial regression coefficient; TGS: Toe grip strength; HGS: Hand grip strength.

Table 4: Association between toe grip strength and physical performance in boys.

Physical performance		Regression coefficient	SE	β	p value	Adjusted R^2
25-m sprint run	Intercept	11.99	1.30		<0.01	0.45
	Age, months	-0.45	0.13	-0.30	<0.01	

	Height, cm	-0.02	0.02	-0.11	0.37	
	Weight, kg	0.02	0.03	0.06	0.59	
	HGS, kg	-0.12	0.04	-0.27	<0.01	
	TGS, kg	-0.10	0.04	-0.20	<0.01	
5-m shuttle run	Intercept	40.43	4.56		<0.01	0.36
	Age, months	-1.61	0.45	-0.33	<0.01	
	Height, cm	-0.10	0.06	-0.19	0.14	
	Weight, kg	0.26	0.12	0.25	0.03	
	HGS, kg	-0.32	0.14	-0.22	0.02	
	TGS, kg	-0.30	0.12	-0.18	0.02	
Standing long jump	Intercept	-10.96	28.7		0.70	0.38
	Age, months	7.03	2.81	0.23	0.01	
	Height, cm	0.41	0.40	0.13	0.31	
	Weight, kg	-0.24	0.73	-0.04	0.75	
	HGS, kg	1.31	0.85	0.14	0.13	
	TGS, kg	3.26	0.77	0.32	<0.01	
Tennis ball throw	Intercept	-4.17	3.05		0.17	0.26
	Age, months	0.29	0.30	0.10	0.33	
	Height, cm	0.07	0.04	0.22	0.11	
	Weight, kg	-0.05	0.08	-0.08	0.53	
	HGS, kg	0.27	0.09	0.30	<0.01	
	TGS, kg	0.09	0.08	0.09	0.30	

SE: Standard error; β : Standardized partial regression coefficient; TGS: Toe grip strength; HGS: Hand grip strength.

Table 5: Association between toe grip strength and physical performance in girls.

Discussion

The primary findings of our study were that TGS increased with age in months, with no between sex differences over the age range of our study group. In addition, TGS was significantly associated with the 25-m sprint run, 5-m shuttle run and standing long jump, regardless of age in months, anthropometric data and HGS, for both sex, with exception of the 5-m shuttle run in boys.

Ikeda and Aoyagi [22] also reported an increase in TGS between 4 and 5 years of age, with no between sex difference. Similarly, a linear increase in HGS was also reported in children from 3 to 5.5 years, with no significant difference between boys and girls [20]. The comparable strength in preschool boys and girls is explained by the absence of significant between sex differences in muscle fiber diameter and muscle mass in children before puberty [23].

On multivariate linear regression analysis, TGS was associated with age in months and weight, but not with sex or height, with the absence of an effect of sex having been presented in the previous paragraph. Of note, TGS in adults is associated to both weight and height [8]. It could

be that the change in height from 4 to 6 years is relatively low, and comparable between girls and boys. That might be why our results did not coincide with these findings in adults.

TGS was significantly associated with performance on the 25-m sprint run, 5-m shuttle run and standing long jump, regardless of age in months, anthropometrics, sex, and HGS, with the exception of the 5-m shuttle run in boys. These are all tasks which are determined, in large part, by lower extremity muscle strength. Morita et al. [10] reported a significant association between TGS and performance on the 50-m sprint run, standing long jump and repeated side step in Japanese third and fifth grade elementary school children, with our results being in agreement. Toes can generate propulsive force during walking and running in adults [2,3] and toe flexor strength is an important factor to enhance jump performance [24]. A similar contribution of the TGS to propulsive force would be expected in preschool children and, therefore, it is logical that TGS was significantly associated with the 25-m sprint, 5-m shuttle run and standing long jump performance in our study. HGS, which is considered to be an indicator of overall muscle strength, was also

significantly associated, as expected, with the 25-m sprint, 5-m shuttle run and standing long jump. In a similar way, as the tennis ball throw requires strength and coordination of the upper limbs and trunk, we did not expect an association with TGS, although performance was significantly associated with HGS.

One of our aims was to demonstrate the utility of TGS to evaluate the development of fundamental physical performance of children between the ages of 4 and 6 years. The rapid improvement in physical performance over this narrow age range is considered to be important with regard to overall child development [22,23]. Yet, a previous study on the development of TGS among preschool children measured the change only at 2 time points, 4 and years of age [22]. In comparison, we subdivided the age range of 4 to 6 years into 5 intervals, demonstrating a progressive increase in TGS across each of these age-intervals. We further evaluated the association between TGS and physical performance, adjusted for age in months, morphological characteristics and HGS, variables that have previously been included in evaluation of the development of TGS [22], demonstrating that TGS was predictive of the physical performance of preschool children, with the exception of the 5-m sprint in boys.

As we used a commercially available toe grip dynamometer, our measurements of TGS are highly reproducible and could be widely applied in practice. This issue of utility is an important limitation of studies which used researcher-developed devices to measure TGS. Moreover, the TGS measurements could be reliably obtained in preschool children, with our ICC (1,2) of 0.90 (95% CI, 0.88-0.92) considered to be excellent based on the criterion of Landis and Koch [21] who reported an ICC >0.81 to be indicative of almost perfect test-retest reliability. Ikeda and Aoyagi [22] also reported high reliability and validity for the measurement of TGS in preschool children. Therefore, our measurement of TGS could be easily implemented in schools for the measurement of physical performance development among preschool children.

The limitations of our study need to be acknowledged. The principal limitation of our study was the possible bias in our sampling, which was limited to Japanese children living in suburbs, who volunteered to participate, attended preschool, and were from a narrow age range, namely 4 to 6 years old. Differences in the development of TGS could be expected among children who are homeschooled and living in regions of different levels of urbanization. Therefore, future studies are needed to evaluate our findings across a more generalized population of preschool children. Children in western populations tend to wear shoes indoors, whereas the Japanese population does not. This cultural difference may also affect the early development of TGS in children. As well, our relatively small sample size may have limited estimations of age and sex related differences. Ambulatory activity and participation in sports are likely to influence, or to be influenced, by TGS; yet we did not assess activity levels or participation in sports. Further studies are needed to obtain descriptive data on a broader population of children over a greater age range, from different racial groups and socioeconomic backgrounds.

In conclusion, our results indicate that TGS increases over the age range of 4 to 6 years in a similar way in both girls and boys. In addition, TGS was significantly associated with physical performance on the 25-m sprint run, 5-m shuttle run and standing long jump performance. Therefore, TGS could be a useful predictor of physical performance for specific sports activities (e.g. sprinting and jumping) in preschool children, supplementing the utility of HGS.

Conflict of Interest

The authors have no conflicts of interest to declare.

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