

The Reliability and Validity of Toe Grip Strength as an Index of Physical Development in 4- to 5-Year-Old Children

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Abstract: Studies on TGS (toe-grip strength) are currently proliferating as a result of the development of the dynamometer. The purpose of the present study was to investigate the reliability and validity of TGS as a physical function in preschool aged children. The participants were 153 preschoolers. Each participant was measured in terms of his or her TGS and completed a MAT (motor ability test). The reliability of the measurements was investigated via Pearson's r and Cronbach's α through a test-retest method, as well as a Bland-Altman plot. The validity of the TGS value was investigated by measuring the correlation between TGS and each component of the MAT, the principal component analysis, and a two-way layout ANOVA with general linear model (gender and age). All reliability coefficients were more than 0.70. Though all components of the MAT relating to TGS were found to be significant ($P < 0.05$), these correlations were weak. However, TGS was found to be a physical function that relating to the lower limbs and develops with aging. Therefore, TGS was found to be a highly reliable measure of physical function performance in preschoolers.

Key words: General linear model, item analysis, motor ability test, physical function, preschooler.

1. Introduction

Uritani et al. [1] reported that TGS (toe-grip strength) declines with age in adults aged 20-79 years, as well as other elements of physical fitness. Other studies have focused on TGS as a measure of fall-related physical function performance among elderly people [2], and human could walk without slip on slippery surfaces with greater TGS as adaptation strategies [3]. Furthermore, Misu et al. [4] reported that TGS is associated with walking speed in elderly people, while Soma et al. [5] found that the toe-gripping action stimulates femoral muscle activity and that the electromyography of the biceps femoris was significantly higher than that of the rectus femoris in young females. Thus TGS is related to various physical and motor functions.

Studies on growth and development in Japan have, in relation to the foot, principally researched aspects such as the height or extent of the arch of the foot. Bare foot education has in fact been recommended practice in Japan since the 1980s, but any benefits pertaining to it have not been scientifically ascertained [6-8]. This problem proves that the index for identifying function of foot has not tried or tested yet. In adults, however, there is no proven relation between a person's shape, such as the height of the foot arch, and physical function performance, such as the power of the lower limb muscles[9]. Equally, in elementary school students, Morita et al. showed that the height of the foot arch is irrelevant to TGS and to performance involving lower limbs, but that TGS does have a bearing on performance involving lower limbs [10]. Moreover, a Japanese domestic study on children confirmed that TGS develops with age and is unaffected by gender difference [11]. These results

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showed that pointing function rather than form is more important in terms of the development of a child's foot and required investigation on physical function including TGS from young children. However, it should be noted that research on preschool aged children is of insufficient quantity, because TGS is not recognized as an index of physical function. While the reliability [12, 13] and validity [14] of TGS as a measure of physical function performance have been examined, the participant samples included only adults. Few studies involved item analysis on TGS pertain to children. This study therefore aimed to redress this by investigating the reliability and validity of TGS as a measure of physical development in preschoolers.

2. Methods

2.1 Participants

The participants were 153 preschoolers aged 4-5 years (4.35 ± 0.50 yr.). Table 1 shows the participants according to their gender and age. No developmentally disabled children participated in this study.

2.2 Measurement Items

Each participant was measured using the dynamometer (T.K.K.3360., Takei Scientific Instrument Co., Japan) shown in Fig. 1. Each participant's right and the left foot were tested alternately twice. TGS may be measured with the subject in either one of two distinct postures: standing [10], or sitting in a chair [1, 4, 5, 15]. Yamada et al. [16] concluded that standing posture, as well as sitting posture, requires considerable power in terms of TGS. In the present study, standing posture was adopted because it enabled the preschoolers to better express the full extent of their strength. In addition, all participants completed a MAT (motor ability test) comprising six items: GS (grip strength, kg), SJ (side jump, times), LDT (long distance throwing, m), SBJ (standing broad jump, cm), S & R (sit-and-reach, cm), 3 m SR (shuttle run, seconds). Table 2 shows the

procedure applied to each MAT item. GS was tested as well as TGS, and the mean of the best scores pertaining to both hands recorded. The other five items constituting the MAT were measured twice, and the best score recorded. The steps taken in the course of PA (physical activity) were checked for 41 subjects aged 5 years using the three-axis pedometer (PWEX-300, TANITA Co., Japan) and tested over the three discontinuous days per week permitted by preschool. PA measurements, on the other hand, were extracted over a 7-day period. The reliability and validity of the pedometer were examined by Ikeda and Aoyagi [17].

2.3 Data Analysis

The reliability of the measurements was investigated by applying Pearson's product-moment correlation coefficient (Pearson's r) and Intra correlation coefficient (Cronbach's α) using a test-retest method on both the right foot and the left foot. The possibility of systematic errors, including fixed bias and proportional bias, were tested via the Bland-Altman analysis [18-20]. The fixed bias implied by the difference between two measurement values (y -value) was investigated using a 99% coefficient interval (99% CI). If zero was included within the 99% CI, the existence of a fixed bias was

Table 1 Participants according to preschoolers' gender and age.

	Boys	Girls	Sub-total
4 yr.	30	39	69
5 yr.	41	43	84
Sub-total	71	82	153



Fig. 1 Toe grip strength dynamometer (T.K.K.3360).

Table 2 MAT (motor ability test) items.

Item (unit)	Method
Grip strength (kg)	Gripping instrument by right and left hands one after other.
Side jump (times)	Number of times of side-jumping between two mats in 10 seconds.
Long distance throwing (0.5 m)	Distance a T-ball thrown (overhand throw).
Standing broad jump (cm)	Distance of jumping.
Sit-and-reach (cm)	Distance reached while sitting on floor, legs extended, reaching towards toes.
3m shuttle run (1/10 seconds)	Duration of time to run and bring three bean bags one by one.

Table 3 Reliability of TGS.

	Right	Left
<i>r</i>	0.720	0.740
<i>α</i>	0.837	0.850

r: Pearson's correlation coefficient.

α: Cronbach's coefficient.

confirmed. The proportional bias shown in the relationship between the *y*-value and the means of the two measurement values (*x*-value) was investigated using a no-correlation test. In this test, if the *x*-value was found to significantly relate to the *y*-value, the existence of a proportional bias in the data would be confirmed. Pearson's *r* was calculated by applying TGS to each component of the MAT, and TGS and steps taken in the course of PA for investigating criterion-related validity. Principal component analysis was applied in order to determine factorial validity. The validity of TGS as a component of physical function performance in preschoolers was investigated by applying a two-way layout ANOVA with GLM (general linear model).

3. Results

3.1 Reliability

The mean TGS for boys was 3.96 ± 1.30 kg (4 yr.) and 5.38 ± 1.57 kg (5 yr.). For girls, the mean TGS was 3.92 ± 1.20 kg (4 yr.) and 4.81 ± 1.11 kg (5 yr.). The reliability coefficients are shown in Table 3. Pearson's *r* for TGS was 0.720 (right) and 0.740 (left), and Cronbach's *α* was 0.837 (right) and 0.850 (left). Fig. 2 shows the Bland-Altman plot. Regarding the investigation into fixed bias and systematic error, the 99% CI pertaining to the difference of the two measurement values was calculated and determined to be -0.44/0.06 for the right foot and -0.29/0.17 for the left. Zero was included in the CI for both feet. The investigation into proportional bias found no significant relationship between the *x*-value and the *y*-value in both the right ($r = -0.014$, $p = 0.862$) and left ($r = 0.026$, $p = 0.747$) foot.

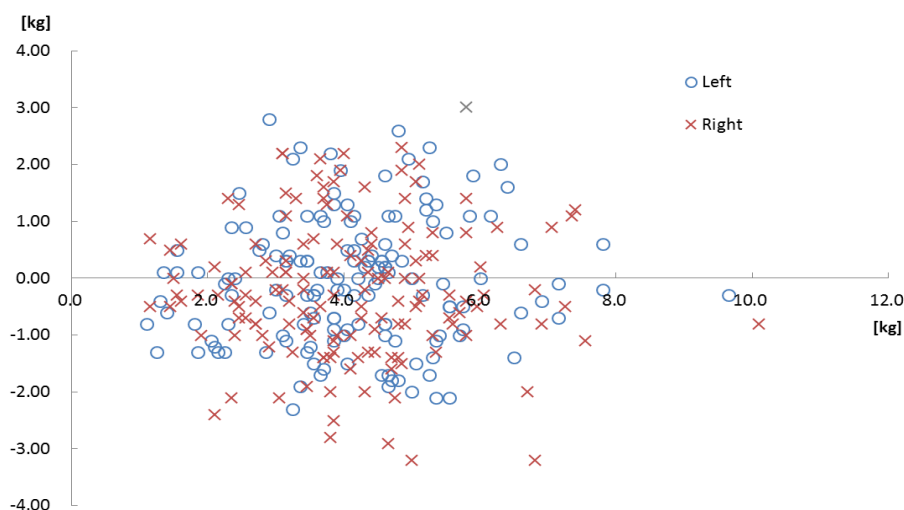
**Fig. 2** Bland-Altman plot.

Table 4 Validity of TGS.

Test item (MAT)	<i>r</i>	<i>p</i>
Grip strength	0.553	**
Side jump	0.422	**
Long distance throwing	0.470	**
Standing broad jump	0.363	**
Sit-and-reach	0.204	*
3m shuttle run	-0.418	**

** $p < 0.01$ * $p < 0.05$.

Table 5 Principal component analysis.

Test item	Principal component loading	Communality
Side jump	0.815	0.664
Standing broad jump	0.834	0.696
Long distance throwing	0.739	0.547
3m shuttle run	-0.846	0.716
TGS	0.657	0.431
Eigen value	3.055	
Proportion (%)	61.1	

3.2 Validity

Significant correlations were observed between TGS and all components of the MAT ($p < 0.05$), as shown in Table 4. The largest coefficient was in relation to GS ($r = 0.553$), while the smallest was in relation to S & R ($r = 0.204$). No relationship was found between TGS and PA in children aged 5 years old on the first day ($r = -0.041$, $p = 0.816$). On the second and third days, however, a positive relationship was observed at the 5% level (r : 2nd = 0.408, 3rd = 0.363). Principal component analysis was applied to 5 items, including TGS and 4 MAT items involving the lower limbs: SJ, LDT, SBJ and SR. The subsequent results showed 3.055 for the first principal component of the eigenvalue and 61.1% for proportion. The highest principal component loading value of each item is shown in Table 5. Fig. 3 shows that the eigenvalue of the first principal component was larger than the other. In other words, all the selected test items were similar as a consequence of the physical function involving the lower limbs and the first principal component being a compound variable of that function. Fig. 4 shows the results of the

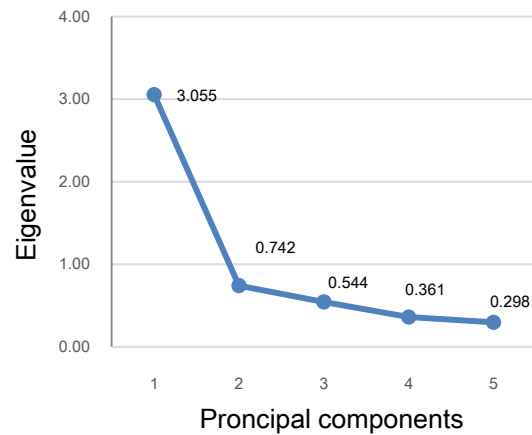


Fig. 3 Eigenvalues of each principal component.

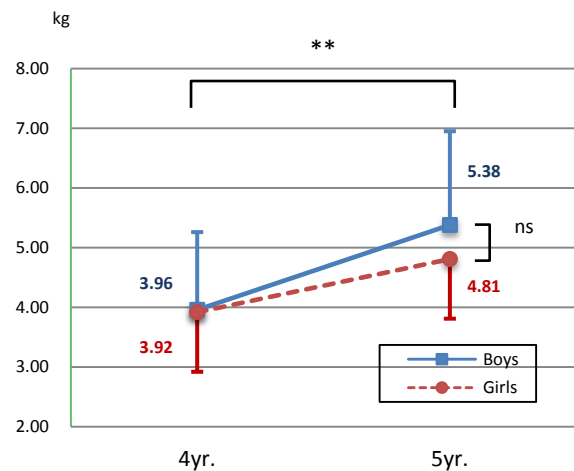


Fig. 4 Two-way layout ANOVA with GLM.

two-way layout ANOVA with GLM by gender and age. There was no interaction between gender and age ($F [1, 149] = 1.578$, $p = 0.211$). An age difference was observed ($F [1, 149] = 29.432$, $p < 0.01$), but no gender difference was recorded ($F [1, 149] = 2.032$, $P = 0.156$).

4. Discussion

The two kinds of reliability coefficient constituted by Pearson's r and Cronbach's α were more than 0.70 for both the right and left foot. Fukumoto et al. [12] reported that TGS was a highly reliable index in young adults and that, in adults, a reliability coefficient in the range of 0.80-0.90 is required in the motor ability test.

In preschoolers, however, a score of 0.60 is acceptable due to the unstable nature of the data they return [21]. Therefore, a range of reliability coefficients pertaining to TGS is permissible. The investigation into systematic error based on the Bland-Altman plot found that the 99% CI of y -values included zero and that these were not biased in either a positive or negative direction. In addition, x -values bore no relation to y -values. In short, there were no fixed or proportional biases between the first and second scores. These results suggest that the measurement values for TGS returned by preschool children were reliable.

Though all components of the MAT relating to TGS were found to be significant ($p < 0.05$), these correlations were weak. Seki et al. [11] suggested that TGS is related to all items of the physical fitness test for elementary school children. The result of the present study supports this suggestion, though participants are preschooler. The investigation into age and gender differences, no gender difference was recorded but an age difference was apparent between the 4 year-old and 5 year-old participants. Malina et al. [22] reported that differences between boys and girls probably reflect, in part, the types of activities available and gender-based societal expectations. It is, however, difficult for TGS to be influenced by the type of activity or by societal expectations. Seki et al. [11] reported that there is no gender difference in terms of TGS among elementary school children. Furthermore, Ogaki et al. [23] also confirm that there is no gender difference though TGS is significantly affected by age among 4- to 5-year-old children. Thus TGS may be regarded as a variable index of preschoolers' physical development unaffected by gender differences and proportionate to the obvious physical changes occurring with age.

The most significant correlation was that observed between TGS and grip strength. This result also supports the study by Seki et al. [11] and may be regarded as a consequence of the palmar grasp reflex

exhibited by infants diminishing over time and eventually becoming inhibited by higher brain centers or integrated into movement patterns as those centers develop [22]. The plantar grasp develops in a similar manner, though the function of the hands and the feet differ in humans. Therefore, TGS and grip strength exhibit the most significant correlation among all the components of the MAT, but not the largest correlation coefficient.

In terms of the relationship between TGS and PA in children aged 5, the steps data show a positive relation to TGS and suggest that children who are vigorously active develop superior TGS. The Pearson's r value between TGS and LDT was 0.470 and is larger than the equivalent value for GS. Though LDT is a manipulation skill involving the higher limbs, it also involves the stabilization of the lower limbs. TGS is a physical function relating not only locomotor skill, but also to the stability required for the execution of a manipulation skill. Morita et al. [10] reported that TGS was the most significant correlating factor for physical performance involving the lower limbs. Regarding factors relating to the lower limbs, principle component analysis was applied based on TGS and selected MAT items. These test items were integrated into one principle component. Accordingly, TGS emerges as the principal validating factor relating to the stability of the lower limbs.

5. Conclusion

For the purposes of item analysis relating to the TGS of preschool aged children, 153 preschoolers were subjected to MAT and PA and their achievement levels were recorded. The reliability and validity were investigated and validated via a stringent series of tests involving Pearson's product-moment correlation coefficient, the intra correlation coefficient, the Bland-Altman plot, a principle component analysis, and a two-way layout ANOVA with GLM. The present study found that TGS may be applied as a highly reliable index of physical development in

preschoolers. TGS was found to be unaffected by gender difference but proportionately and appropriately sensitive to aging, and may therefore be referred to as the significant item in terms of measuring the function of the foot in preschool aged children. TGS is therefore considered to be a valid indicator of physical development for preschooler.

References

- [1] Uritani, D., Fokumoto, T., Matsumoto, D. and Shima, M. 2014. "Reference Values for Toe Grip Strength among Japanese Adults Aged 20 to 80 Years: A Cross-Sectional Study." *Journal of Foot and Ankle Research* 7: 1-6. Accessed December 1, 2014. <http://www.jfootankleres.com/content/7/1/28>.
- [2] Yamaji, S., and Demura, S. 2013. "Reliability and Fall Experience Discrimination of Cross Step Moving on Four Spots Test in the Elderly." *Archives of Physical Medicine and Rehabilitation* 94 (7): 1312-9.
- [3] Fong, D. T., Mao, D. W., Li, J. X., and Hong, Y. 2008. Greater Toe Grip and Gentler Heel Strike Are the Strategies to Adapt to Slippery Surface." *Journal of Biomechanics* 41 (4): 838-44.
- [4] Misu, S., Doi, T., Asai, T., Sawa, R., Tsutsumimoto, K., Nakakubo, S., Yamada, M., and Ono, R. 2014. "Association between Toe Flexor Strength and Spatiotemporal Gait Parameters in Community-Dwelling Older People." *Journal of Neuro-Engineering and Rehabilitation* 11: 1-6.
- [5] Soma, M., Murata, S., Kai, Y., Nakae, H., and Satou, Y. 2014. "Activity of the Femoral Muscles during Toe-Gripping Action." *Journal of Physical Therapy Science* 26: 1619-21.
- [6] Aoyagi, N., Uchiyama, Y., Kobayashi, Kobayashi, M., Shibawaka, T., and Eto, T. 1999. "The Effects of Barefoot Education in Elementary Schools on Safety and Health Behavior Modifications." *Japanese Journal of Health and Human Ecology* 65 (4): 173-81. (in Japanese)
- [7] Kawashima, K., Shimizu, A., and Yamazaki, S. 1997. "Consciousness of Kindergarten Day Nursery about Bare Foot Education of an Infant and the Examination." *Memoirs of Ashikaga Junior College* 17: 41-7. (in Japanese)
- [8] Terada, M., Ikada, Y., Kanai, H., and Hachisuka, H. 1985. "Effect of Prolonged Barefooted Life Growth in School Children (Report1)." *Bulletin of Kyoto University of Education, ver. B* 67: 15-23. (in Japanese)
- [9] Lizis, P., Posadzki, P., and Smith, T. 2010. "Relationship between Explosive Muscle Strength and Medial Longitudinal Arch of the Foot." *Foot and Ankle International* 31 (9): 815-22.
- [10] Morita, N., Yamauchi, J., Kurihara, T., Fukuoka, R., Otsuka, M., Okuda, T., Ishikawa, N., Nakajima, T., Nakamachi, R., Matsuno, S., Kamiie, S., Shide, N., Kambayashi, I., and Shinkaiya, H. 2014. "Toe Flexor Strength and Foot Arch Height in Children." *Medical and Science in Sports and Exercise*. Accessed December 1, 2014. <http://graphics.tx.ovid.com/ovftpdfs/FPDDNCFBMDMG BN00/fs046/ovft/live/gv025/00005768/00005768-900000 000-98019.pdf> (Published Ahead-of-Print).
- [11] Seki, K., Yoneshima, M., and Nishida, A. 2014. "Relationship between Toe Grip Muscle Strength of Elementary School Student and Physical Fitness and Life Style." *Regional Studies: Tottori University Journal of the Faculty of Regional Sciences* 10 (3): 135-44. (in Japanese)
- [12] Fukumoto, T., Uritani, D., Maeoka, H., Okada, Y., and Matsumoto, D. 2011. "Development of a Toe Grip Dynamometer." *Bulletin of Kio University* 13: 31-5. (in Japanese)
- [13] Uritani, D., Fokumoto, T., and Matsumoto, D. 2012. "Intrarater and Interrater Reliabilities a Toe Grip Dynamometer." *Journal of Physical Therapy Science* 24 (8): 639-43.
- [14] Hirahara, S. 2011. "Examination of Validity of Machine That Measures Muscular Power of Digitus Pedis." *Waseda Journal of Human Sciences* 24: 91. (in Japanese)
- [15] Kurihara, T., Yamauchi, J., Otsuka, M., Tottori, N., Hashimoto, T., and Isaka, T. 2014. "Maximum Toe Flexor Muscle Strength and Quantitative Analysis of Human Plantar Intrinsic Imaging Technique." *Journal of Foot and Ankle Research* 7: 1-6. Accessed December 1, 2014. <http://www.jfootankleres.com/content/7/1/26>
- [16] Yamada, K., Sumita, N., and Sudo, A. 2013. "The Effect of Posture for Toe Grip Strength." In *Proceedings of the 64th Conference in Japan Society of Physical Education, Health and Sports Science*, 275. (in Japanese)
- [17] Ikeda, T., and Aoyagi, O. 2013. "The Validity and Reliability of a Three-Axis Pedometer for Measuring Preschool Children's Physical Activity." Presented at the 6th Asia-Pacific Conference on Exercise and Sports Science, Taipei, Taiwan.
- [18] Altman, D. G., and Bland, J. M. 1983. "Measurement in Medicine: the Analysis of Method Comparison Study." *The Statistician* 32: 307-71.
- [19] Bland, J. M. and Altman, D. G. 1986. "Statistical Method for Assessing Agreement between Two Methods of Clinical Measurement." *Lancet* 327 (8476): 307-10.
- [20] Bland, J. M., and Altman, D. G. 1999. "Measuring Agreement in Method Comparison Study." *Statistical Methods in Medical Research* 8 (2): 135-60.
- [21] Ikeda, T., and Aoyagi, O. 2008. "Relationships between

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Test Characteristics and Movement Patterns, Physical Fitness, and Measurement Characteristics: Suggestions for Developing New Test Items for 2- to 6-Year-Old Children.” *Human Performance Measurement* 5: 9-22.

- [22] Malina, R. M., and Bouchard, C. 1991. *Growth, Maturation, and Physical Activity*. Champaign: Human

Kinetics.

- [23] Ogata, D., Shimada, Y., and Seki, K. 2012. “The Research of Motor Abilities and Fundamental Movements of Young Children Who Received Childcare Close to Nature.” *Regional Studies: Tottori University Journal of the Faculty of Regional Sciences* 9(2): 16-24. (in Japanese)