Research Paper

Hong Kong Physiotherapy Journal
Vol. 39, No. 2 (2019) 143–150
DOI: 10.1142/S1013702519500136

Hong Kong Physiotherapy Journal
http://www.worldscientific.com/worldscinet/hkpj

Relationships between lower extremity strength and the multi-directional reach test in children aged 7 to 12 years

Benjaporn Hirunyaphinun, Soontharee Taweetanalarp* and Anong Tantisuwat

Department of Physical Therapy, Faculty of Allied Health Sciences
Chulalongkorn University, 154 Rama 1 Rd., Pathumwan, Bangkok 10330, Thailand

**soontharee.t@chula.ac.th*

Received 26 July 2018; Accepted 12 August 2019; Published 13 September 2019

Objective: This study investigates the relationships between the Multi-Directional Reach Test (MDRT) and lower extremity strength in typical children.
Methods: The MDRT including forward, backward, leftward, and rightward directions was measured in 60 children aged between 7 and 12 years old with typical development. The lower extremity muscle groups were measured using a hand-held dynamometer.
Results: The reaching score in each direction had positive relationships with the strengths of several lower extremity muscle groups ($r = 0.26$ to $0.52, p < 0.05$). Only the strengths of the hip flexor and knee flexor muscles significantly correlated with the MDRT scores in all directions ($r = 0.26$ to $0.50, p < 0.05$).
Conclusion: This study highlights the strength of the hip and knee flexor muscle groups as being important domain to control balance in all directions. These findings may be used for therapists in planning a balance program to improve the limits of stability.

Keywords: Multi-Directional Reach Test; lower extremity strength; typical children; limits of stability.

Introduction

Balance is a fundamental skill for all movements in humans, such as activities involving standing, reaching, walking, running, or jumping.[1] Balance is defined as the ability to control the body's center of gravity relative to the base of support or limits of stability either at standing or during movement, which is achieved through the integrated action of musculoskeletal and neurological systems.[2,3] The development of the ability to balance in children is

*Corresponding author.

represented as a stage-like progression. The growth and maturation of the body systems in human follow a general developmental timeline.[4] Therefore, the development of the ability to balance in children is represented as a stage-like progress, which occurs through the development of specific systems involved in balance control abilities such as visual, vestibular, somatosensory, and musculoskeletal systems.[5–7] One factor that has direct influence on the ability to control balance, and also improvements in children, is muscle strength.[8,9] Several studies found that muscle strength, especially lower extremity muscle strength, is highly correlated with postural control or balance in the standing position.[3,9,10] The weakness of lower extremity muscles is a common factor associated with balance impairment that is a risk factor for postural instability and falling.[9,11–13]

Problems in postural control may cause reduced mobility in children and also restrict participation in the community.[14] By the age of 7–12 years, as middle childhood, the balance control in this age is still emerging as adult-like balance patterns but the balance is not yet fully completed.[15–17] Children are more prone to falls because of the variability in their movements with several immature body systems such as the musculoskeletal systems and neuromuscular system.[7] Postural impairment leading to falls in children may result in functional limitations, loss of confidence, and low self-esteem.[18] The fear of falling can also have adverse effects on the psychological and social development of the child.[19,20] Approximately 43% of child injuries in Asia in those aged 0–18 years were caused by falls.[19] Therefore, balance examination helps to investigate balance status and provides intervention to children with the risk of falling. The Multi-Directional Reach Test (MDRT) is one performance-based test in clinical balance assessment that measures the maximal reach distance in four directions including the forward, backward, leftward, and rightward directions during standing with the feet stationary.[20,21] Greater reach distance represents larger limits of stability, which indicates better balance ability.[20,21] The test can be easily completed by children requiring simple equipment. MDRT also yields results which can be interpreted quickly. It has also been shown to be reliable (ICC = 0.93 to 0.95) and valid (concurrent validity of MDRT with Berg Balance Scale; $r = 0.36$ to 0.48 and Timed Up and Go test; $r = 0.26$ to 0.44) for measuring dynamic standing balance.[21] Although most studies involving the MDRT were commonly used to assess balance in the elderly,[21–23] some studies had reported the functional reach and lateral reach tests in children.[1,14,24] A recent study investigated the normative reference scores using the MDRT in children.[20] Additionally, previous studies have reported correlations between muscle strength and clinical balance testing (e.g., Functional Reach Test, Berg Balance Scale, and Timed Up and Go test) in adults and the elderly.[25–27] Researchers found that reduced muscle strength may lead to a fall during dynamic tasks including reaching movements.[25,26,28] Although previous studies reported the effects of muscle strength on the functional reach test,[29,30] no study has documented the contributions of lower extremity strength in the MDRT. This finding attempts to investigate the relationship between lower extremity strength and the MDRT in children to provide the preliminary data for promoting health or rehabilitation.

The aim of this study was to examine the relationship between lower extremity strength and the MDRT for reaching distances. The strength of muscle groups might influence balance in different directions. This would enhance clinicians in planning rehabilitation program for improving the ability to control balance in specific directions.

Materials and Methods

Sixty participants, aged between 7 and 12 years (30 boys, 30 girls), were recruited from two schools in the Bangkok metropolitan region. These children were recruited using the convenience sampling technique with equal numbers of boys and girls for each age (boys = 5, girls = 5; $n = 10$). Children participated in this study were able to understand and follow commands. Exclusion criteria included children who (1) had any medical problems affecting their ability to stand or complete the tasks, (2) had musculoskeletal, balance, or visual problems that might affect balance and strength, and (3) had history of injuries or surgeries on the lower extremities. The information sheet, medical questionnaire, and consent form were given to the parents. All parents and children signed the informed consent forms which were approved by the University Ethics Review Committee for Research Involving Human Research Subjects.

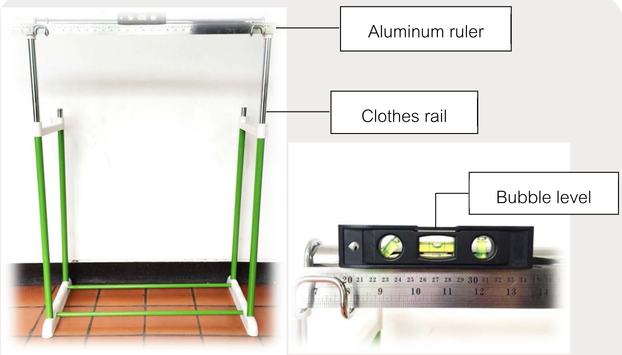

Fig. 1. MDRT tool including a meter stick made of aluminum and a bubble level.

After consent was given to participate in the study, anthropometric data including height and weight were collected for each child. Then, the MDRT was assessed in four directions randomly determined by computer. The MDRT tool included a meter stick made of aluminum and a bubble level used to ensure the meter stick was placed horizontally upon the floor (Fig. 1). Before measuring the MDRT, each child was instructed to stand barefoot on a piece of paper fixed to the floor and to take up a stance approximately a shoulder-width apart. The feet position was traced onto the paper to ensure the same starting point for all tests. The meter stick was set to the height of each child's acromion process. Test procedures were explained and demonstrated by the same tester. Then, the children were instructed to raise an outstretched arm to shoulder level and "reach as far (direction given) as possible without losing balance and without touching the ruler. For the backward direction, the children were instructed to "lean backward as far as possible". The difference in the distances between the middle fingertip at starting and ending positions was used as the reaching score. An average of three successful trials in each direction was used for the analysis. A fourth trial was only conducted for subjects if they lost their balance or took a step during the testing in one of the trials. If did so twice, they were excluded from the study. The MDRT in this study was the high inter-rater reliability ($\text{ICC} = 0.80 - 0.86$) and intra-rater reliability ($\text{ICC} = 0.89 - 0.97$) in all directions. For the inter-rater reliability, 10 children who were 7–12 years old were recorded by two raters who are physical therapists. The first rater recorded three trials in each direction, considering the average of the three times for the calculation. The second rater recorded the same measurement. The subjects took a rest of 5 min between the raters. For the intra-rater reliability, the same children were re-tested the following week. All of the procedures which were previously explained were repeated during the re-test. However, the MDRT was performed before the measurement of lower extremity strength to avoid any fatigue that may occur.

Lower extremity strength was measured using a hand-held dynamometer (HHD; model 01165 Lafayette Manual Muscle Test System, Lafayette Instrument Company, Lafayette, USA) that was set to read force in Newtons (N). Muscle strength was tested by using the isometric break test in eight muscle groups, comprising (a) hip flexor, (b) hip extensor, (c) hip adductor, (d) hip abductor, (e) knee flexor, (f) knee extensor, (g) ankle dorsiflexor, and (h) ankle plantar flexor. The testing procedure followed Ibrahim *et al.*[9] and Eak *et al.*[31] as shown in Table 1. Standardized instruction was given to all children to "try to hold the testing position and do not let me push or pull your leg" by the other tester (the 2nd tester) to blind between testers. Inter-rater and intra-rater reliabilities using the HHD in this study were of high reliability ($\text{ICC} = 0.83 - 0.89$, $\text{ICC} = 0.93 - 0.99$), respectively. For the inter-rater reliability, 10 children who were 7–12 years old were measured by two raters who are physical therapists. The first rater recorded three trials in each muscle group, considering the maximum force of three times for analysis, and resting 1 min between trials. The second rater recorded the same measurement. The subjects were given a rest of 5 min between raters. For the intra-rater reliability, the same children were re-tested the following week. All of the procedures which were previously explained were repeated during the re-test.

All children received an explanation of the procedures and practiced once with submaximal force to ensure correct performance. Participants were tested for three trials in each muscle group, and rested 1 min between trials to avoid possible fatigue.

Statistical Analysis

Statistical analysis was performed with IBM SPSS Statistics (version 22.0) for Windows. Normality of data distribution was defined by the Kolmogorov–Smirnov test. Descriptive statistics were obtained

Table 1. Procedure of lower extremity strength testing.

No.	Muscle group	Testing position	Child stabilization	Dynamometer placement
(1)	Hip flexor	Supine, hip and knee flexed 90°	Trunk	Mid-point on the anterior side of the distal femur (10 cm above the base of patella)
(2)	Hip extensor	Supine, hip, and knee flexed 90°	Trunk	Mid-point on the posterior side of the distal femur (same level as HF)
(3)	Hip adductor	Supine, hip, and knee extended	Trunk and the other leg	Medial side of the distal femur (same level as HF)
(4)	Hip abductor	Supine, hip, and knee extended	Trunk and the other leg	Lateral side of the distal femur (same level as HF)
(5)	Knee flexor	Sitting, hip, and knee flexed 90°	Thigh	Posterior side of the distal tibia (10 cm above the lateral malleolus)
(6)	Knee extensor	Sitting, hip, and knee flexed 90°	Thigh	Anterior side of the distal tibia (same level of KF)
(7)	Ankle dorsiflexor	Supine, hip, knee extended and ankle in neutral position	Lower limb proximal to ankle	Dorsum of foot proximal to the metatarsophalangeal joint
(8)	Ankle plantar flexor	Supine, hip, knee extended and ankle in neutral position	Lower limb proximal to ankle	Sole of foot proximal to the metatarsophalangeal joint

for the values of the MDRT and lower extremity strength. Pearson product-moment correlation coefficient was used to examine the relationships between lower extremity strength and the MDRT in each direction. The strength of correlation in this study was considered as follows: good to excellent correlation (> 0.75), moderate to good correlation (0.51 to 0.75), fair correlation (0.25 to 0.50), and little to no correlation (< 0.25).[32] Statistical significance was considered at $p < 0.05$.

Results

The characteristics of participants for each age group are shown in Table 2. Table 3 shows the mean MDRT scores in each direction and lower extremity strength values among the children aged 7–12 years. The data on muscle strength were obtained from the average of both limbs. The relationships between lower extremity strength and the MDRT in each direction, as shown in Table 4, showed that the reaching score in each direction correlated with several muscle groups. In the forward direction, the results of Pearson's correlation revealed a fair correlation between the forward reaching score and the strength of the hip flexor, hip extensor, knee flexor, knee extensor, and ankle plantar flexor muscle groups ($r = 0.27$ to 0.31, all $p < 0.05$). In the backward direction, fair correlation was found between the backward reaching score and the strength of all lower extremity muscle groups ($r = 0.30$ to 0.50, $p < 0.05$); in particular, the hip abductor revealed moderate correlation with the backward reaching score ($r = 0.52$, $p < 0.001$). Additionally, fair correlation was observed between the leftward reach distance and the strength of the hip flexor, hip extensor, hip abductor, knee flexor, and knee extensor muscle groups ($r = 0.29$ to 0.36, p-value < 0.05). Also, the rightward reach distance showed a fair correlation

Table 2. Characteristics of the participants.

Age (year)	7 ($n = 10$) (mean ± SD)	8 ($n = 10$) (mean ± SD)	9 ($n = 10$) (mean ± SD)	10 ($n = 10$) (mean ± SD)	11 ($n = 10$) (mean ± SD)	12 ($n = 10$) (mean ± SD)
Height	122.0 ± 3.5	127.7 ± 2.5	134.6 ± 5.4	137.2 ± 3.4	142.9 ± 4.3	147.9 ± 5.8
Weight	24.5 ± 3.2	25.3 ± 2.6	29.3 ± 3.5	34.1 ± 4.7	36.7 ± 4.8	39.3 ± 4.5

Table 3. Results of the MDRT (cm) and lower extremity strength (N) values.

Age (year)	7 ($n = 10$) (mean ± SD)	8 ($n = 10$) (mean ± SD)	9 ($n = 10$) (mean ± SD)	10 ($n = 10$) (mean ± SD)	11 ($n = 10$) (mean ± SD)	12 ($n = 10$) (mean ± SD)	Mean (mean ± SD)
Forward (cm)	11.3 ± 2.6	10.5 ± 3.2	11.1 ± 2.3	11.8 ± 1.4	12.1 ± 2.3	11.9 ± 2.5	11.4 ± 2.4
Backward (cm)	6.8 ± 2.0	6.2 ± 1.4	6.9 ± 1.3	9.1 ± 2.5	8.7 ± 1.7	10.1 ± 2.6	7.8 ± 2.3
Leftward (cm)	9.3 ± 0.9	9.9 ± 2.2	9.4 ± 1.8	9.9 ± 1.3	10.3 ± 2.1	9.9 ± 1.5	9.6 ± 1.9
Rightward (cm)	9.1 ± 1.2	9.1 ± 2.5	9.1 ± 1.8	10.1 ± 1.7	9.6 ± 0.8	10.7 ± 2.6	9.6 ± 1.7
Hip flexors (N)	120.2 ± 14.6	121.1 ± 18.8	135.3 ± 23.8	144.7 ± 17.8	174.6 ± 25.5	178.5 ± 29.5	145.7 ± 31.7
Hip extensors (N)	274.1 ± 50.7	224.1 ± 53.8	258.7 ± 76.3	290.6 ± 30.1	315.8 ± 74.9	332.3 ± 69.9	282.6 ± 69.0
Hip adductors (N)	94.4 ± 20.3	105.7 ± 22.4	130.1 ± 27.5	131.1 ± 18.6	155.6 ± 43.1	159.3 ± 47.2	129.4 ± 38.7
Hip abductors (N)	124.1 ± 17.3	118.9 ± 21.5	144.7 ± 32.8	150.4 ± 22.7	182.6 ± 36.8	194.7 ± 48.5	152.6 ± 41.4
Knee flexors (N)	100.1 ± 14.3	112.7 ± 14.0	130.1 ± 25.1	141.4 ± 17.5	157.9 ± 34.0	163.1 ± 36.2	134.2 ± 33.2
Knee extensors (N)	149.8 ± 20.7	139.7 ± 29.0	173.1 ± 52.7	207.1 ± 41.1	212.7 ± 51.5	234.9 ± 45.7	186.2 ± 53.0
Ankle dorsiflexors (N)	145.6 ± 19.4	139.6 ± 23.8	164.9 ± 27.4	189.5 ± 21.9	212.2 ± 40.8	213.1 ± 40.3	177.5 ± 41.5
Ankle plantarflexors (N)	411.1 ± 61.3	354.2 ± 87.1	417.9 ± 115.7	453.6 ± 70.3	439.1 ± 84.2	515.4 ± 41.6	440.9 ± 93.9

Table 4. Relationships between lower extremity strength and the MDRT in each direction.

Variables	MDRT Forward	Backward	Leftward	Rightward
Hip flexors	0.28*	0.48**	0.33*	0.28*
Hip extensors	0.28*	0.42**	0.36**	0.24
Hip adductors	0.15	0.43**	0.20	0.09
Hip abductors	0.21	0.52**	0.30**	0.21
Knee flexors	0.27*	0.50**	0.29*	0.26*
Knee extensors	0.27*	0.48**	0.32*	0.25
Ankle dorsiflexors	0.20	0.44**	0.21	0.27*
Ankle plantar flexors	0.31*	0.30*	0.26	0.32*

Notes: *statistically significant, $p < 0.05$, **statistically significant, $p < 0.001$.

with the strength of the hip flexor, knee flexor, ankle dorsiflexor, and ankle plantar flexor muscle groups ($r = 0.26$ to 0.32, $p < 0.05$).

Discussion

This is the first study to investigate the relationship between lower extremity strength and the MDRT score in children. The results of Pearson's correlation showed that the lower extremity strength in several muscle groups fairly correlated with the MDRT scores.

In the forward direction, the reaching score correlated best with the strength of the ankle plantar flexor muscle group. The eccentric plantar flexion of the ankle controls the anterior lean distance without falling. This relationship can be explained by the mechanical demands of preventing the falling forward of the trunk during the forward reaching task.[10,28,33,34] This finding is consistent with the results of Daubney and Culham,[10] who identified the strength of the ankle plantar flexor muscle as contributing to the prediction of the forward reaching score. The other possible explanation would involve the direction specific muscles in the caudal–cranial direction. In standing position, the muscles change into a distal-to-proximal recruitment order caused by the body parts near the support surface being in the need of stabilization.[35]

Additionally, the results of this study indicated significant correlation between the strength of the hip and knee muscle groups in the sagittal plane and the distance of the forward reach test. It is possible that the agonistic and antagonistic muscles of the hip and knee took the pattern of coactivation which assisted the stabilization of postural control. The activity of the hip extensor group assists the knee extensor muscles to control the knee positions and to prevent excessive trunk flexion.[36] The strength of the hip flexor muscle group is important for the balance and functional performance that is used to restore equilibrium to change the postural control.[37] According to the previous studies, researchers suggested that the knee extensor muscle group comprises the anti-gravity muscles necessary to perform balance control and functional activities in standing.

The decrease in knee extensor strength is the one factor influencing falls.[38–40] Also, the strength of the knee flexor group acts mainly to prevent hyperextension of the knee during forward reaching.[33] The activity patterns of knee flexor muscles including the semimembranosus, semitendinosus, and biceps femoris while performing the reach test may act mainly as a breaking function in the forward direction.[41] This finding demonstrated that the agonist–antagonist muscles might activate coordinately the surrounding knee joint. However, both proximal and distal muscles are recruited equally in younger ages, but with increasing age, distal muscles become more activated.[33,42]

The strength of the hip and knee flexor muscles is not only significantly correlated with forward reaching score but also in lateral reaching scores. One possible explanation may be that the hip flexor muscle group including the two major portions of iliacus and psoas originates from the iliacus bone and lumbar spine, respectively, and inserts on the trochanter of the femur. In a standing position, the specific function of the iliacus muscle is important to stabilize between the pelvis and hip joints. The psoas muscle assists in stabilizing the lumbar spine in the frontal plane.[43] This means that the iliopsoas muscle may act mainly as a stabilizer muscle when performing the reaching task in the lateral direction. Also, hip abductor muscles are crucial to minimize pelvic rotation and maintain balance in the frontal plane.[36]

However, the left and right reaching tasks demonstrated correlations with different muscle groups. One possible explanation may be the familiarity with the dominant reaching of the activity in daily life. All participants in this study preferred the use of right hand for reaching. Possibly, rightward reaching makes it easier to control the center of mass (COM) within the base of support. The strength of the distal muscles following dorsiflexor and plantar flexor muscles would provide adequate stabilization during reaching. Conversely, leftward reaching must exert hip and knee extension strength to help maintain reaching balance in this task. Knee extensor strength correlated with dynamic postural stability and influence on functional task performance.[44] However, in order to clarify the mechanism of these strategies, the kinetic parameter and muscle activity in each lower extremity should be further studied.

In the backward direction, it is interesting that there was a significant correlation between the backward reaching score and the strength of all lower extremity muscle groups. The results revealed that the magnitude of correlations was quite similar. This implies that the reaching performance in the backward direction needs to coordinate the strength of all muscle groups for achieving the reaching task. The reasons for these correlations may result from the backward reaching being a more difficult task that is unfamiliar and that has no visual acuity.[20,23] Most daily activities that have better balance control are performed in front of the body.[20] The difficulty of the balance task relates to the recruitment of the antagonistic muscles and the modulation of the degree of contraction.[41] Antagonistic coactivation is a phenomenon in the development of postural adjustments.[7] Muscle co-contraction increases when balance is more challenged[45] and decreases when the task is easier.[46] Therefore, leaning backwards may require a lot of effort to control the body without falling. This could be the reason for the relatively low reach scores in the backward direction. In addition, from a biomechanical perspective, the hip extension angle is much smaller than the hip flexion angle. It may result in the backward reaching score lesser than forward reaching score.

Accordingly, this study demonstrates that hip and knee flexor strength significantly correlated with reach scores in all directions. Therefore, therapist should pay attention to the strength of the hip and knee flexor muscle groups in children to improve the limits of stability through balance training in all directions. However, results of this study show that the MDRT was weakly correlated with lower extremity strength. One possible explanation would involve the position of testing. The MDRT was performed during standing but the muscle strengths were tested in supine or sitting position. Nevertheless, in this study, we only examined the muscle strength of the lower extremities. Trunk muscles might affect the reaching task in the four directions. A further study could investigate the strength of the trunk muscles and muscle recruitment differences of MDRT in children with movement disorders.

Conclusion

The results of our study demonstrated that the strength of the lower extremity muscle groups is correlated with the MDRT in each direction. This study indicated that the strength of the hip and knee flexor muscle groups was implicated in increased reaching in four directions. This may be helpful for therapists in planning rehabilitation programs to improve the limits of stability.

Conflict of Interest

The authors have no conflict of interest relevant to this paper.

Funding/Support

This study was funded by the 90th Anniversary of Chulalongkorn University. The authors are very thankful to all the children who dedicated themselves to participating in the study. We also acknowledge the principal and teachers at Sriwittayapaknam school and Nidhiprinya school for their kind permission and facilities toward the data collection.

Author Contributions

Collecting data, analysis of data, and manuscript writing were carried out by Hirunyapinun. Analysis of data, critical discussion, revising manuscript, and management of the study were carried out by Taweetanalarp. Tantisuwat contributed to critical discussion and revising manuscript.

References

1. Deshmukh AA, Ganesan S, Tedla JS. Normal values of functional reach and lateral reach tests in Indian school children. Pediatr Phys Ther 2011;23:23–30.
2. Horak FB. Clinical measurement of postural control in adults. Phys Ther 1987;67(12):1881–5.
3. Shumway-Cook A, Woollacott MH. Motor control: Translating research into clinical practice. 4th ed. Philadelphia: Lippincott Williams & Wilkins, 2012:161–80.
4. Cech DJ, Martin ST. Functional movement development across the life span. 3rd ed. Philadelphia: W.B. Saunders, 2012:12–4.
5. Assaiante C, Mallau S, Viel S, Jover M, Schmitz C. Development of postural control in healthy children: A functional approach. Neural Plast 2005;12 (2–3):109–18.
6. Westcott SL, Burtner PA. Postural control in children: Implications for pediatric practice. Phys Occup Ther Pediatr 2004;24(1–2):5–55.
7. Woollacott MH, Shumway-Cook A. Changes in posture control across the life span—A systems approach. Phys Ther 1990;70(12):799–807.
8. Chen T, Chou LS. Effects of muscle strength and balance control on sit-to-walk and turn durations in the timed up and go test. Arch Phys Med Rehabil 2017;98(12):2471–6.
9. Ibrahim AI, Muaidi QI, Abdelsalam MS, Hawamdeh ZM, Alhusaini AA. Association of postural balance and isometric muscle strength in early- and middle-school-age boys. J Manipulative Physiol Therapeut 2013;36(9):633–43.
10. Daubney ME, Culham EG. Lower-extremity muscle force and balance performance in adults aged 65 years and older. Phys Ther 1999;79(12):1177–85.
11. Nevitt MC, Cummings SR, Kidd S, Black D. Risk factors for recurrent nonsyncopal falls: A prospective study. JAMA 1989;261(18):2663–8.
12. Society AG, Society G, Prevention OF, Panel OS. Guideline for the prevention of falls in older persons. J Am Geriatr Soc 2001;49(5):664–72.
13. Tinetti ME, Williams TF, Mayewski R. Fall risk index for elderly patients based on number of chronic disabilities. Am J Med 1986;80(3):429–34.
14. Yuksel E, Ozcan Kahraman B, Nalbant A, Kocak UZ, Unver B. Functional reach and lateral reach tests in Turkish children. Phys Occup Ther Pediatr 2017;37(4):389–98.
15. Schmid M, Conforto S, Lopez L, Renzi P, Alessio TD. The development of postural strategies in children: A factorial design study. J Neuroeng Rehab 2005;2(1):29.
16. Kirshenbaum N, Riach C, Starkes J. Non-linear development of postural control and strategy use in young children: A longitudinal study. Exp Brain Res 2001;140(4):420–31.
17. Shumway-Cook A, Woollacott MH. The growth of stability: Postural control from a development perspective. J Mot Behav 1985;17(2):131–47.
18. Bart O, Bar-Haim Y, Weizman E, et al., Balance treatment ameliorates anxiety and increases self-esteem in children with comorbid anxiety and balance disorder. Res Dev Disabil 2009;30:486–95.
19. Hyder AA, Sugerman D, Ameratunga S, Callaghan JA. Falls among children in the developing world: A gap in child health burden estimations? Acta Paediatr 2007;96(10):1394–8.
20. Sharma K, Samuel AJ, Midha D, Aranha VP, Narkeesh K, Arumugam N. Multi-directional reach test in South Asian children: Normative reference scores from 5 year to 12 years old. Homo 2018;69 (1–2):62–9.

21. Newton RA. Validity of the multi-directional reach test: A practical measure for limits of stability in older adults. J Gerontol A Biol Sci Med Sci 2001;56 (4):M248–52.
22. Holbein-Jenny MA, Billek-Sawhney B, Beckman E, Smith T. Balance in personal care home residents: A comparison of the berg balance scale, the multi-directional reach test, and the activities-specific balance confidence scale. J Geriatr Phys Ther 2005;28(2):48–53.
23. Tantisuwat A, Chamonchant D, Boonyong S. Multi-directional reach test: An investigation of the limits of stability of people aged between 20–79 years. J Phys Ther Sci 2014;26(6):877–80.
24. Norris RA, Wilder E, Norton J. The functional reach test in 3- to 5-year-old children without disabilities. Pediatr Phys Ther 2008;20(1):47–52.
25. Choi JS, Kang DW, Seo JW, Kim DH, Yang ST, Tack GR. Fall- and BBS-related differences in muscle strength and postural balance of the elderly. J Phys Ther Sci 2016;28(9):2629–33.
26. Lee DK, Kanf MH, Lee TS, Oh JS. Relationships among the Y balance test, Berg Balance Scale, and lower limb strength in middle-aged and older females. Braz J Phys Ther 2015;19(3):227–34.
27. Shimada H, Kim H, Yoshida H et al., Factors associated with the timed up and go test score in elderly women. J Phys Ther Sci 2010;22(3):273–8.
28. Melzer I, Benjuya N, Kaplanski J, Alexander N. Association between ankle muscle strength and limit of stability in older adults. Age Ageing 2009;38(1):119–23.
29. Cheng SJ, Yang YR, Cheng FY, Chen IH, Wang RY. The changes of muscle strength and functional activities during aging in male and female populations. Int J Gerontol 2014;8:197–202.
30. Kligyte I, Lundy-Ekman L, Medeiros JM. Relationship between lower extremity muscle strength and dynamic balance in people post-stroke. Medicina 2003;39(2):122–8.
31. Eek MN, Kroksmark AK, Beckung E. Isometric muscle torque in children 5 to 15 years of age: Normative data. Arch Phys Med Rehabil 2006;87 (8):1091–9.
32. Portney LG, Watkins MP. Foundations of clinical research applications to practice. 3rd ed. New Jersey: Pearson Education, 2009:524–5.
33. Maranesi E, Di Nardo F, Rabini RA et al., Muscle activation patterns related to diabetic neuropathy in elderly subjects: A functional reach test study. Clin Biomech 2016;32:236–40.
34. Lin SI, Chen YR, Liao CF, Chou CW. Association between sensorimotor function and forward reach in patients with diabetes. Gait Posture 2010;32 (4):581–5.
35. van der Fits IB, Klip AW, van Eykern LA, Hadders-Algra M. Postural adjustments accompanying fast pointing movements in standing, sitting and lying adults. Exp Brain Res 1998;120(2):202–16.
36. Salsich GB, Mueller MJ. Relationships between measures of function, strength and walking speed in patients with diabetes and tansmetatarsal amputation. Clin Rehabil 1997;11(1):60–7.
37. Aoyama M, Suzuki Y, Onishi J, Kuzuya M. Physical and functional factors in activities of daily living that predict falls in community-dwelling older women. Geriatr Gerontol Int 2011;11(3):348–57.
38. Cheng SJ, Yang YR, Cheng FY, Chen IH, Wang RY. The changes of muscle strength and functional activities during aging in male and female populations. Int J Gerontol 2014;8(4):197–202.
39. Akbari M, Mousavikhatir R. Changes in the muscle strength and functional performance of healthy women with aging. Med J Islam Repub Iran 2012;26(3):125–31.
40. Ikezoe T, Asakawa Y, Tsutou A. The relationship between quadriceps strength and balance to fall of elderly admitted to a nursing home. J Phys Ther Sci 2003;15(2):75–9.
41. Hadders-Algra M, Carlberg EB. Postural control: A key issue in developmental disorders. 1st ed. New Jersey: Wiley-Blackwell, 2008:45–55.
42. Kuo AD, Zajac FE. A biomechanical analysis of muscle strength as a limiting factor in standing posture. J Biomech 1993;26:137–50.
43. Andersson E, Oddsson L, Grundstrom H, Thorstensson A. The role of the psoas and iliacus muscles for stability and movement of the lumbar spine, pelvis and hip. Scand J Med Sci Sports 1995;5(1):10–6.
44. Nocera JR, Buckley T, Waddell D, Okun MS. Knee extensor strength, dynamic stability, and functional ambulation: Are they related in Parkinson's disease? Arch Phys Med Rehabil 2010;91(4):589–95.
45. Diener HC, Horak FB, Nashner LM. Influence of stimulus parameters on human postural responses. J Neurophysiol. 1988;59(6):1888–905.
46. Horak FB, Shupert CL, Mirka A. Components of postural dyscontrol in the elderly: A review. Neurobiol Aging 1989;10(6):727–38.