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Original article

Oblique direction reach test: a pilot test to measure limits of stability in oblique direction and its psychometric properties

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Background: Activities of daily living require balance in the oblique direction and persons with neurological disorders have balance issues in the oblique direction for performing functional tasks. There is a dearth of literature for assessing dynamic balance in the oblique direction.

Objectives: To establish and report reference values for oblique direction reach tests and to assess the validity and reliability of the oblique direction reach test in Saudi young adults.

Methods: Two hundred and six medical students (120 males, 86 females) were recruited by random sampling for this study. Subjects were measured for distance reached in the oblique, forward, and lateral directions on graph paper, which was mounted on a white board.

Results: The mean and standard deviation for the oblique direction reach was 22.06 ± 7.17 cm. A positive correlation was observed between oblique reach and height with and *r* - value of 0.56 ($P < 0.01$). The intra and inter-rater reliability was shown with intraclass correlation coefficiency values of 0.97 and 0.86, respectively ($P < 0.001$). Concurrent validity with the forward reach test and lateral reach test were shown with *r* - values of 0.78 and 0.73, respectively ($P < 0.01$).

Conclusion: We established the normal values for oblique direction reach tests in Saudi young adults. This test is valid and reliable for measuring the limits of stability in the oblique direction.

Keywords: Balance, oblique reach, normative data, reliability, validity.

Balance is the capacity to control the center of mass in association to the base of support. [1] Balance is a complex process that involves the integration of information from the visual, vestibular, somatosensory, and musculoskeletal systems, and also from higher centers like the brain. [2] Balance can be classified as static and dynamic balance.

Balance is required for maintaining a static posture or for stabilizing a dynamic movement. Therefore, it is a critical component for performing daily activities independently. [3] People with different neurological pathologies such as stroke, traumatic brain injury, Parkinson's disease, multiple sclerosis, cerebellar disorders, cerebral palsy, and intellectual disabilities demonstrate impaired balance. Lack of balance has a profound impact on daily life in performing tasks that are potentially destabilizing such as reaching, lifting, and leaning.[1]

Physical therapy rehabilitation programs focus to restore this balance and thereby improve the activities of daily living. In the clinical setting, valid and reliable outcome measures are available to detect the changes in balance performance.[4]

The gold standard method of assessing balance is by computerized posturography, but it requires sophisticated and expensive equipment and is not commonly available everywhere.[5] There are other clinical measures used in the clinical setting for assessing balance from a functional perspective, they are the Berg Balance Scale, Timed Up and Go Test, Performance Oriented Mobility Assessment, Functional Reach, and Lateral Reach Tests. [1]

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The Functional Reach Test (FRT) is the valid and reliable clinical measure developed by Duncan PW, *et al.*, which assess dynamic balance and indirectly measures the limits of stability. [6, 7] It investigates the maximum distance a subject can reach while maintaining a stable base of support in the forward direction. The Lateral Reach Test (LRT), developed by Brauer S, *et al*. [7], assesses the limits of stability in the medio-lateral direction. Newton developed the multi-directional Reach Test which is a valid and reliable measure. This test is used to measure the extent of balance in the forward, backward, right lateral and left lateral directions in elderly people. [8] Studies also have conducted functional and lateral reach tests to establish normative data in children aged between 6 - 12 years. [9]

However, in activities of daily living the reaching is neither exactly in the forward direction nor exactly in the lateral direction. Most of the time the reach is in the oblique direction for kitchen activities, office desk tasks, and sports events. Based on these observations only, the famous physical therapy approach named Proprioceptive Neuromuscular Facilitation was developed by Knott and Voss. They made their patterns of facilitation in the diagonal and spiral directions rather than in pure coronal or frontal or transverse plane movements. [10]

A recent study on a chronic stroke population had assessed their weight shift in eight different directions including the oblique direction. While reaching all these directions, they measured the center of pressure excursions. As per their findings, the lowest movement of the center of pressure was observed in the affected side in the posterior lateral direction followed by the affected side in the posterior, and then the affected anterior lateral direction. These findings also indicate that the reach in the oblique direction is more affected than the pure anterior or lateral directions. [11]

Hence a clinical balance tests examining the limits of stability in the oblique direction is needed. The testing should reflect the ability to control the body in the oblique direction. After thorough searching of the literature, we found that there is a dearth of research regarding an oblique reach testing as an isolated balance measurement. The aim of the current research was to develop oblique direction reach test (ODRT) and to report its psychometric properties.

Materials and methods

Participants

This observational study was approved by the research ethics committee, King Khalid University (REC # 2016-08-29). The total number of subjects was 206, of these 120 were males and 86 were females. All of them were medical students and were recruited for the study by the random sampling method using a random number table. Both gender subjects with ages of 20 – 23 years were included in the study. All of them were medical students and their average age was 21.41 ± 1.11 years. Exclusion criteria were subjects who could not sustain raised arms at 90^0 of the oblique direction, had a history of back or lower extremity surgery, had musculoskeletal problems, had muscular weakness, or had any deformities.

Measurements

Written consent form were obtained from the subjects who were interested and agreed to participate in the study after an explanation of the purpose of the study. All of the subjects underwent measurements for the in height, and weight with a stadiometer and weighing machine respectively. Body mass index (BMI) were calculated with the values of height and weight. Upper limb length was measured from the anterior angle of the acromion to the tip of the radial styloid process. [12] Lower limb length was measured from the anterior superior iliac spine to the medial malleolus in centimeters.[13] The distance between the anterior superior iliac spine to the acromion process was considered the trunk length and measured by inch tape and the value taken in centimeters.[14]

Procedure

Graph paper was pasted to a movable whiteboard. [15] The subject was standing in a relaxed position with legs shoulder width apart without shoes. The whiteboard was arranged 45 degrees from the forward center in the anterior-lateral direction. The subjects were asked to raise their right arm to 90 degrees in the oblique anterior-lateral direction between flexion and abduction. The arm should be parallel with the graph paper on the whiteboard. The placement of a pen mark at the end of the tip of the third metacarpal along the graph paper was recorded as the starting position. Individuals then reached as far obliquely as they could reach without taking a step, touching the board, lifting heels, or bending knees. They kept the hand along the graph paper for 2 - 3

seconds. The placement of a pen mark at the tip of the third metacarpal on the graph paper recorded the end position. The distance between the two positions was measured in centimeters. The details of the ODRT procedure can be seen in Figure 1. Initially, all the subjects were given a practice trial, followed by three actual trails. The average of the 3 trails was taken for data analysis purposes. The forward and lateral reaches were done in a similar fashion, only the board position was changed to anterior or lateral to suit the reach direction.

After measuring the reach distance in the forward, lateral, and oblique directions, subjects took a 10-minute period of rest and researcher measured the distance in the oblique direction for three trails and the average was taken for analyzing intra-rater reliability. Another researcher measured in the distance in the oblique direction the next day for analyzing inter-rater reliability. Concurrent validity of the ODRT was done with the values of forward reach distance and lateral reach distance.

Figure 1. Oblique direction reach test measurement procedure. (A) Start Position (B) End Position.

Statistical analysis

Statistical Package for Social Science version 21 was used for analysis and $P < 0.05$ at 95 % confidence interval (CI) was kept as significant. Mean and standard deviation (SD) of demographic data, upper limb length, lower limb length, trunk length, and the reach distances were analyzed using descriptive statistics. The correlation of oblique reach with height, weight, BMI, gender, upper limb length, lower limb length, and trunk length was analyzed by Pearson correlation and with regression analysis. Inter-rater and intra-rater reliability was analyzed by intraclass correlation coefficient (ICC) and Bland-Altman graphs. We analyzed the concurrent validity of oblique reach with forward reach and lateral reach using ICC. The mean and standard deviation of males and females were compared using unpaired student *t* - test.

Results

The demographic characteristics like height, weight, body mass index, upper limb length, trunk length, and lower limb length were analyzed using descriptive statistics and their mean ± SD values were reported in Table 1.

ODRT was measured in centimeters and the minimum reach value obtained was 9 cm and maximum reach value was 42.5 cm. The total mean ± SD of oblique reach distance was 22.06 ± 7.17 cm. The details of each age and gender group are shown in Table 1. Comparison of oblique reach distances between males and females was performed with unpaired student *t* - test, and there was a significant difference between males and females in reach distance ($P < 0.001$). The males had greater oblique reach distances than the females.

The correlation between height, weight, body mass index, upper limb length, trunk length, lower limb length, and oblique reach distance was done using Pearson correlation coefficient. There was a modest correlation observed between height, lower limb length, and upper limb length, with oblique reach distance with *r* - values 0.56, 0.45, and 0.38, respectively ($P < 0.001$). The details of all the correlations are provided in Table 2. Regression analysis revealed there are no factors affecting the oblique direction reach. The details of regression analysis are shown in Table 3.

Table 1. Mean ± standard deviations of demographic characteristics and oblique direction reach values for male, female and total subjects of the study.

Age	Gender	No. S	Height (Meters)	Weight (kg)	BMI (kg/mt^2)	ULL (cm)	TL (cm)	LLL (cm)	ODRT (cm)
20	Male	26	1.69 ± 0.07	69.12 ± 15.39	24.04 ± 5.04	58.79 ± 8.53	48.46 ± 3.00	92.52 ± 4.05	24.57 ± 6.73
	Female	33	1.57 ± 0.06	56.03 ± 10.80	22.18 ± 4.22	52.86 ± 3.09	47.89 ± 9.33	83.70 ± 7.56	15.81 ± 3.47
	Total	59	1.63 ± 0.09	61.80 ± 14.47	23.00 ± 4.65	55.47 ± 6.74	48.14 ± 7.21	87.58 ± 7.62	19.67 ± 6.74
21	Male	31	1.71 ± 0.05	73.19 ± 16.21	25.09 ± 5.08	57.19 ± 2.26	48.61 ± 3.39	91.90 ± 4.86	24.73 ± 5.56
	Female	15	1.55 ± 0.04	53.37 ± 12.72	21.60 ± 4.34	52.93 ± 2.62	45.17 ± 4.54	84.93 ± 4.02	18.11 ± 4.73
	Total	46	1.66 ± 0.09	66.73 ± 17.72	23.95 ± 5.08	55.80 ± 3.10	47.49 ± 4.09	89.63 ± 5.63	22.57 ± 6.11
22	Male	34	1.72 ± 0.19	72.34 ± 16.53	24.84 ± 6.33	57.06 ± 3.02	48.79 ± 3.48	91.09 ± 4.15	26.40 ± 6.94
	Female	23	1.56 ± 0.04	54.02 ± 12.85	21.52 ± 4.79	53.33 ± 3.08	45.17 ± 4.20	84.74 ± 2.61	18.12 ± 4.41
	Total	57	1.66 ± 0.17	64.95 ± 17.55	23.50 ± 5.95	55.55 ± 3.54	47.33 ± 4.16	88.53 ± 4.77	23.06 ± 7.27
23	Male	29	1.69 ± 0.05	75.34 ± 17.24	26.28 ± 5.69	57.66 ± 2.72	50.84 ± 3.03	91.07 ± 4.16	27.40 ± 6.86
	Female	15	1.58 ± 0.04	58.67 ± 14.39	23.07 ± 4.96	53.81 ± 3.82	47.97 ± 2.68	84.47 ± 4.00	15.74 ± 2.79
	Total	44	1.65 ± 0.07	69.66 ± 18.03	25.18 ± 5.61	56.34 ± 3.60	49.86 ± 3.20	88.82 ± 5.15	23.42 ± 8.02
Whole	Male	120	1.70 ± 0.11	72.59 ± 16.32	25.08 ± 5.59	57.61 ± 4.61	49.17 ± 3.35	91.60 ± 4.31	25.81 ± 6.56
Whole	Female	86	1.57 ± 0.05	55.49 ± 12.28	22.06 ± 4.48	53.16 ± 3.12	46.70 ± 6.62	84.33 ± 5.37	16.82 ± 3.98
Total	Total	206	1.65 ± 0.11	65.45 ± 16.99	23.82 ± 5.35	55.75 ± 4.61	48.14 ± 5.11	88.57 ± 5.97	22.06 ± 7.17

Note: BMI: Body Mass Index; LLL: Lower Limb Length; No. S: number of subjects; ODRT: Oblique Direction Reach Test; TL: Trunk Length; ULL: Upper Limb Length

Table 2. Correlation *r* - values between subject characteristics and oblique reach distance.

Variable	Oblique reach distance (n = 206 subjects)	
	***r* - value**	***P* - value**
Gender	- 0.62	< 0.001
Age	0.19	0.01
Height	0.56	< 0.001
Weight	0.35	< 0.001
Body Mass Index	0.19	0.01
Upper Limb Length	0.38	< 0.001
Trunk Length	0.22	< 0.001
Lower Limb Length	0.45	< 0.001

Table 3. Regression analysis values for comparison between demographic characteristics and oblique reach distance.

Variable	Oblique reach distance (n = 206 subjects)			
	B	**SE**	**β**	**Significance**
Gender	- 6.48	1.26	- 0.45	< 0.001
Age	0.73	0.36	0.11	0.04
Height	22.07	15.88	0.26	0.17
Weight	- 0.10	0.13	- 0.23	0.47
Body Mass Index	0.24	0.36	0.18	0.51
Upper Limb Length	0.06	0.12	0.04	0.63
Trunk Length	0.04	0.09	0.03	0.66
Lower Limb Length	0.00	0.11	0.00	0.97

Note: B: Unstandardized Beta; β: Standardized Beta; SE: Standard Error

The psychometric properties like intra-rater reliability, inter-rater reliability, and concurrent validity were analyzed. The intra-rater reliability analysis showed a strong intraclass correlation with an *r* - value of 0.97 (95% CI 0.96 to 0.98) with a significance value of less than 0.001. The results of intra-rater reliability are shown in the Bland-Altman plots in Figure 2. This plot shows consistency between the two measurements made by the same researcher as most of the values came within the upper and lower limits of mean differences.

The inter-rater reliability analysis showed a high intraclass correlation (*r* - value 0.86, (95% CI 0.71 to 0.93) ($P < 0.001$). The results of inter-rater reliability are shown in the Bland-Altman plot in Figure 3. This plot shows consistency between two measurements taken by two different researchers as most of the values came within the upper and lower limit of mean differences.

The concurrent validity was calculated between forward reach and oblique reach, lateral reach and oblique reach distances, and their *r* - values were 0.78 and 0.73, respectively, showing the high concurrent validity for the ODRT.

Discussion

Based on the normal patterns of functional movements we have designed this innovative ODRT. Performance of functional tasks such as operating an elevator, handling kitchen appliances, reaching for shelves, eating with a fork, operating a wall-mounted phone all require balance.[16] This balance is based on the limits of stability, which means the maximum distance a person can displace the center of gravity out of the base of support from a midline vertical position in any direction without losing balance or taking a step or any support.[17]

The oblique reach test assesses one's ability to displace their center of gravity out of the base of support in an oblique direction without taking a step or taking any kind of support. In the study of the Park SH, [11] he assessed center of pressure excursions among chronic stroke patients in various directions in standing positions. The various directions involved were anterior, anterior-lateral, lateral, posterior-lateral and posterior of the affected and non-affected side. They found that the most common direction affected was posterior followed by posterior-lateral followed by anterior-lateral. Even though posterior and

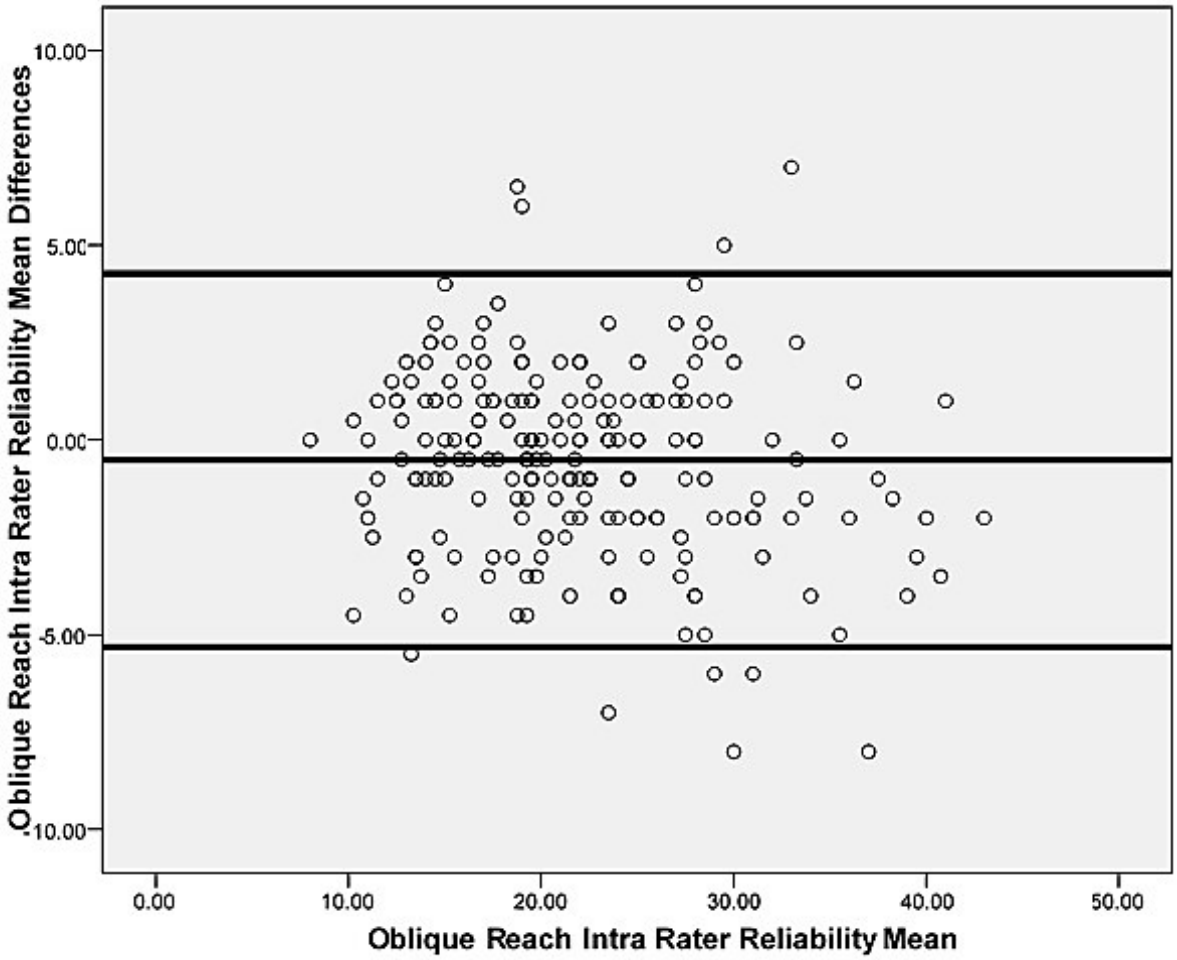

Figure 2. Oblique direction reach test intra-rater reliability. ($r = 0.97$; $P < 0.001$)

posterior-lateral direction reaches were most affected, in day-to-day life reaching in these directions is not very common. So measuring forward and lateral displacements without oblique displacement not accurately estimate the patients balance involvement.

Ganesan M, *et al.*, conducted a study on finding the limits of stability in various directions among subjects with multiple sclerosis and healthy controls. They assessed center of gravity sway on limits of stability tests in eight directions: forward, forward right (oblique), right (lateral), backward right, backward, backward left, left (lateral), and forward left (oblique). In all of these directions, they measured reaction time, movement velocity, endpoint excursion, maximal excursion, and direction control. The authors found less reaction time and direction control, more endpoint excursion and maximal excursion in the oblique reach direction than the forward and lateral reach directions both in subjects with multiple sclerosis and healthy controls. [18] These observations also stress the importance of measuring oblique direction reach distances.

Liaw MY, *et al.* also conducted a similar study to test the limits of stability on computerized dynamic post-urography in 107 youths, middle-aged, and elderly healthy individuals. They tested the limits of stability in eight different directions: forward, right-forward (oblique), right (lateral), right-backward, backward, left-backward, left (lateral), and left-forward (oblique). In each direction, they measured reaction time, and direction control. The reaction time was less in the right and left-forward than forward in all the age groups. The directional stability of right and left-forward direction was less than the forward and lateral directions in all the age groups.[19] This also provides distinctness of measuring oblique direction reach distances.

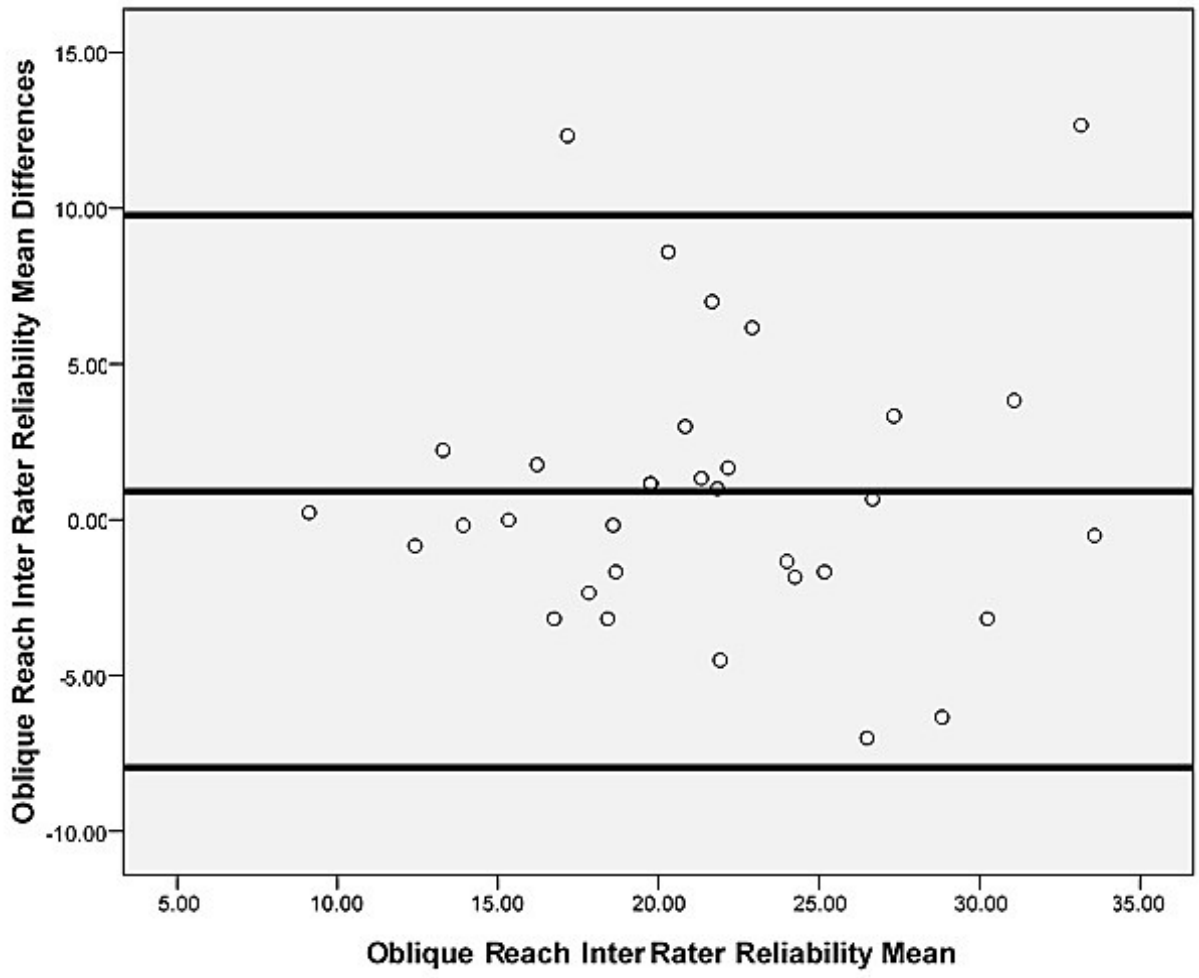

Figure 3. Oblique direction reach test inter- rater reliability. ($r = 0.86$; $P < 0.001$)

A contemporary study was done to assess the limits of stability in people aged 20 to 79 years. They assessed multidirectional reach in various directions: forward, rightward, backward, and leftward reach. The mean ± SD of age, weight, height, and body mass index for people who were in the 20 to 29 years group was 21.60 ± 1.80 years, 160.10 ± 5.20 cm, 55.30 ± 6.30 kg, 21.60 ± 2.00, respectively. [20] In our study, the mean ± SD of age, weight, height, and body mass index for people who were in the 20 to 23 years group was 21.41 ± 1.11 years, 165 ± 11 cm, 65.45 ± 16.99 kg, 23.82 ± 5.35, respectively. The forward and lateral reach distance mean ± SD values were 28.3 ± 8.1 cm and 17.9 ± 5.2 cm in their study. When we compared our study values, their reach distances were similar to be oblique direction reach distances in this study with a mean ± SD of 22.06 ± 7.17 cm.

The effect of height, upper limb length, and lower limb length on reaching in an oblique direction demonstrated positive moderate correlations ($P < 0.001$). Among them, the height had more of an effect with an *r* - value of 0.56, which means that the taller the subject the longer their reach. When we compared the mean ± SD of oblique direction reach distances between genders we found that males have greater oblique direction reach distances than females. This could be due to stature differences between genders, that is, males have greater height, upper limb length, and lower limb length when compared to the females, so they might have performed better in reaching (Table 1). Similar male-female differences and the effect of height on reach distances were also observed in one study done on Brazilians. [21]

The intra-rater reliability of the functional reach test was assessed in 1161 subjects by Rockwood K, *et al*. and they got a high intraclass correlation coefficient (ICC) value of 0.92. [22] The test re-test reliability of lateral reach tests assessed in 60

elderly women showed an *r* - value of > 0.94.[23] Even in our study, we got a high ICC values for intra-rater reliability of 0.97, showing the consistency of this test. The inter-rater reliability of forward reach was assessed in stroke and healthy subjects by Martins EF, *et al*. They found good and moderate reliabilities of ICC values of 0.787 and 0.653 in stroke and healthy subjects, respectively. [24] In our study, we found good inter-rater reliability with an ICC value of 0.856. This shows good reusability of this test among the therapists.

The founders of functional reach, Duncan PW, *et al*. assessed the concurrent validity of functional reach in comparison with the center of pressure excursion and reported an *r* - value of 0.71.[25] The lateral reach test concurrent validity was assessed in comparison with the Fastrack machine and they got an *r* - value of 0.65.[23] We assessed the concurrent validity of the ODRT values by comparing it with forward reach values and lateral reach values and we found *r* - values of 0.78 and 0.73, respectively. This shows the good validity of the test.

The limitations of the current study were the inability to cover all the age groups and different areas in the country for data collection, and the inability to compare the oblique direction reach values with more sophisticated equipment, like balance master or force plates. Future studies should be conducted in a multicentric manner on all the age groups. The validity comparisons should be done with the center of pressure excursions.

Conclusion

The oblique direction reach test is a unique test which can assess functional balance. The current study conducted this test on 206 healthy individuals (120 males and 86 females) aged between 20 - 23 years. The normative values were presented for each age group, the average oblique direction reach distance observed among them was 22.06 ± 7.17 cm. The intra rater and inter-rater reliabilities were excellent and good with ICC values of 0.97 and 0.856, respectively. The concurrent validity of this oblique direction reach test was compared with forward reach values and lateral reach values and we found good validity with *r* - values of 0.78 and 0.73, respectively.

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Conflict of interest

There is no conflict of interest in this research.

References

1. Shumway-Cook A, Woollacott MH. Motor control: Translating research into clinical practice. 4th ed. Philadelphia, PA: Wolters Kluwer Health/Lippincott Williams & Wilkins; 2007.
2. Muir SW, Berg K, Chesworth B, Klar N, Speechley M. Balance impairment as a risk factor for falls in community-dwelling older adults who are high functioning: a prospective study. Phys Ther 2010;90: 338-47.
3. Lin MR, Hwang HF, Hu MH, Wu HD, Wang YW, Huang FC. Psychometric comparisons of the timed up and go, one-leg stand, functional reach, and Tinetti balance measures in community-dwelling older people. J Am Geriatr Soc 2004;52:1343-8.
4. Desai A, Goodman V, Kapadia N, Shay BL, Szturm T. Relationship between dynamic balance measures and functional performance in community-dwelling elderly people. Phys Ther 2010;90:748-60.
5. Harel NY, Asselin PK, Fineberg DB, Pisano TJ, Bauman WA, Spungen AM. Adaptation of computerized posturography to assess seated balance in persons with spinal cord injury. J Spinal Cord Med 2013;36: 127-33.
6. Kamath T, Sandesh TS. The test retest reliability and concurrent validity of functional reach test in 5 to 15 years old children with down' s syndrome - a cross sectional study. Int J Phys Educ Sports Health 2017; 4:523-9.
7. Tedla JS, Asiri F, Alshahhrani MS, Sangadala DR, Gular K, Rengaramanuam K, Mukherjee D. Reference values of functional and lateral reach test among the young Saudi population: their psychometric properties and correlation with anthropometric parameters. Med Sci Monit 2019;25:5683-9.
8. 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: M248-52.
9. 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.
10. Adler SS, Beckers D, Buck M. PNF in practice: an illustrated guide. 3rd ed. Heidelberg: Springer Medizin Verlag; 2008.
11. Park SH. Assessment of weight shift direction in chronic stroke patients. Osong Public Health Res Perspect 2018;9:118-21.
12. Shah FY, Kotwal HA, Shahid-ul-islam M. Psychogenic limb length discrepancy of upper limbs. Int J Contemp Med Res 2017;4:962-4.
13. Magee DJ. Orthopedic physical assessment. 4th ed. St Louis, MO: Elsevier Saunders; 2006.
14. Egwu MO, Mbada CE, Olowosejeje D. Normative values of spinal flexibility for Nigerians using the inclinometric technique. J Exerc Sci Physiother 2008; 8:32-104.
15. Lord SR, Sherrington C, Menz HB. Falls in older people risk factors and strategies for prevention. Cambridge: Cambridge University Press; 2001.
16. Sprigle S, Maurer C, Holowka M. Development of valid and reliable measures of postural stability. J Spinal Cord Med 2007;30:40-9.
17. Li F. The effects of Tai Ji Quan training on limits of stability in older adults. Clin Interv Aging 2014;9: 1261-8.
18. Ganesan M, Kanekar N, Aruin AS. Direction-specific impairments of limits of stability in individuals with multiple sclerosis. Ann Phys Rehabil Med 2015;58: 145-50.
19. Liaw MY, Chen CL, Pei YC, Leong CP, Lau YC. Comparison of the static and dynamic balance performance in young, middle-aged, and elderly healthy people. Chang Gung Med J 2009;32:297-304.
20. 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; 26:877-80.
21. Silveria KRM, Matash SLA, Perracinin MR. assessment of performance in the functional reach and lateral reach tests in a brazilian population sample. Braz J Phys Ther 2006;10: 381-6.
22. Rockwood K, Awalt E, Carver D, MacKnight C. Feasibility and measurement properties of the functional reach and the timed up and go tests in the Canadian study of health and aging. J Gerontol A Biol Sci Med Sci 2000;55:M70-3.
23. Brauer S, Burns Y, Galley P. Lateral reach: a clinical measure of medio-lateral postural stability. Physiother Res Int 1999;4:81-8.
24. Martins EF, de Menezes LT, de Sousa PH, Araujo Barbosa PH, Costa AS. Reliability of the Functional Reach Test and the influence of anthropometric characteristics on test results in subjects with hemiparesis. NeuroRehabilitation 2012;31:161-9.
25. Duncan PW, Weiner DK, Chandler J, Studenski S. Functional reach: a new clinical measure of balance. J *Gerontol* 1990;45:M192-7.