Title: Development and reliability of "BalanceGrid" and "WalkMeter" to measure limits of balance stability and spatial-temporal gait parameters in people post stroke.

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Abstract

Background: Laboratory tools such as force platform, posturography, and Gaitrite provide precise and accurate information, but are limited in availability due to their high cost and required skilled work force. This necessitates the need for relatively inexpensive, simple and clinically accessible tools to measure the limits of stability and spatial-temporal gait parameters in people post stroke and to establish psychometric properties.

Objective: To develop and determine the internal consistency, intra-rater and inter-rater reliability of BalanceGrid and WalkMeter systems in people post stroke.

Methods: The BalanceGrid system consists of subject and grid interface and the WalkMeter system consists of a 10-meter walkway, a video camera and motion picture analysis software. The applicability of the tools was tested in 40 age-matched healthy volunteers. The internal consistency (Cronbach's alpha), intra-rater and inter-rater reliability (ICC) of the BalanceGrid and WalkMeter tools were established in 47 people post stroke by two raters.

Results: Internal consistency reliability of BalanceGrid and WalkMeter systems was 0.94- 0.99 and 0.86-0.99, respectively. Both the clinical tools showed high intra-rater and inter-rater reliability, with an ICC of 0.82-0.99.

Conclusion: With the high reliability of the BalanceGrid and WalkMeter systems, we recommend these tools to screen and measure the balance and gait in people post stroke.

Key Words: Reliability; Internal consistency; Balance; Gait; Stroke

Introduction

Difficulty in shifting weight towards the paretic side not only affects balance (Bohoman and Lackin., 1985; Caldwell, et al., 1986; Dickstein, et al., 1984; Mizrahi, et al., 1989), but also limits the walking speed in people post stroke (Chitralakshmi, et al., 2009; George, et al., 2005; Olrey, et al., 1994; Olrey, et al., 1996; Patterson, et al., 2008). Currently, there is a wide spectrum of laboratory and clinical utility tools available to measure the limits of balance stability (Clarissa, et al., 2005) and linear gait parameters (Casey, et al., 1998). Gold standards such as force platform, posturography, gait lab, and Gaitrite (Mcdonough, et al., 2011) are a few of the laboratory instruments designed specifically to evaluate balance and gait-related issues in various neurological conditions. Although they are highly sensitive and provide precise and accurate information, their access is limited in clinical settings due to their high cost, extensive assessment and requirement of a skilled work force. Similarly, clinical utility measures and questionnaires evaluating the same parameters but do it qualitatively. This necessitates the need for the development of clinical tools that can assess limits of balance stability and gait parameters with similar, if not identical, accuracy and are affordable.

Swaymeter, a clinically feasible tool, was designed to measure the limits of balance stability; it was compact and lightweight and did not require any technological processing (Sturnicks, et al., 2011). Nevertheless, the authors highlighted that the friction between the pen-paper interfaces in the Swaymeter system could limit its accuracy. Similarly, the paper-dye method, used to measure linear gait parameters, required chalking or inking the subjects' soles as they walk on a paper walkway (Karthikbabu, et al., 2011). Walking on a paper with a sense of the feet being wet and sticky could alter the actual walking speed of people post stroke. Thus, there is a need for relatively inexpensive, clinically feasible tools to overcome the bearing due to the friction and stickiness of the interfaces in the paper-pen and paper-dye methods, respectively. Hence, we designed the BalanceGrid and WalkMeter systems to determine the limits of balance stability and gait parameters in people post stroke. The psychometric properties of these new systems must be evaluated prior to its use in clinical practice. Reliability is one of the basic psychometric properties indicating the consistency of a tool. Thus, we tested the intra- rater and inter-rater reliability, and in turn, their clinical applicability in people post stroke.

Methods

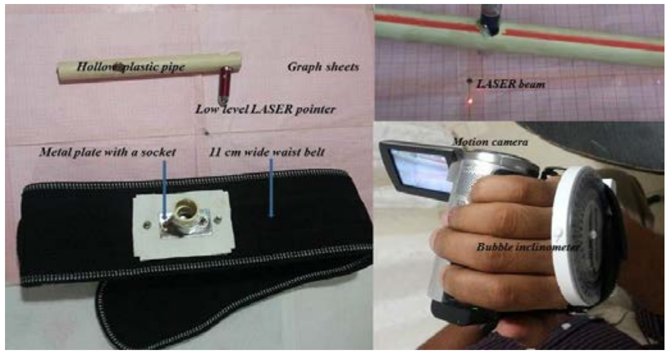
This study was approved by the Institutional review board of Manipal University, India. This cross-sectional design study was conducted in Manipal hospital, Bangalore and in Stroke rehabilitation uit, St. Martha's hospital, India. People with stroke who were referred to physiotherapy were screened, and a written informed consent was obtained.

People with an ability to walk 10 meters independently with or without an assistive device, Brunnstrom recovery stage beyond 3 and with no known neurological diseases such as Parkinson's and/or vestibular lesions, musculoskeletal disorders such as fractures and/or surgery of lower extremities in the previous six months, chronic osteoarthritis affecting balance and walking speed were included. Subjects were excluded from the study if diagnosed with acute medical illness and perceptual dysfunction. To check the applicability of the BalanceGrid and WalkMeter tools, the limits of balance stability and linear gait parameters from 40 age-matched healthy volunteers were determined, and the intra-rater reliability was established. Later, intra-rater and inter-rater reliability of the tools was tested in people with stroke.

Development of BalanceGrid:

The BalanceGrid system consists of graph sheets, paper foot mat, 2-foot wide height adjustable table, 11-cm wide waist belt, a metal plate with a socket, 22-cm long hollow plastic pipe, low-level LASER pointer and a motion camera to capture the sway of the subject (Figure 1).

Figure 1: ***Development of BalanceGrid***



BalanceGrid has a scalar/grid interface and a subject interface. The scalar/grid interface has a graph sheet pasted on the top of the height adjustable table and corresponds to the posterior mid-thigh of the subject. A paper foot mat with soles imprinted one foot apart was placed on the ground 6 inches away from the table to ensure that every subject stands at same distance. The subject interface consists of a 11-cm wide, length adjustable Velcro-based waist belt strapped at the level of anterior superior iliac spine. The belt is riveted with a 10-cm wide metal plate and socket on the rear side of the subject to lodge the 22-cm long hollow plastic pipe. It is ensured that the hollow pipe is parallel to ground at the level of the L5 vertebra. A low level LASER pointer fixed in the hollow pipe is directed downward to project over the graph sheet mounted on the table (Figure 2).

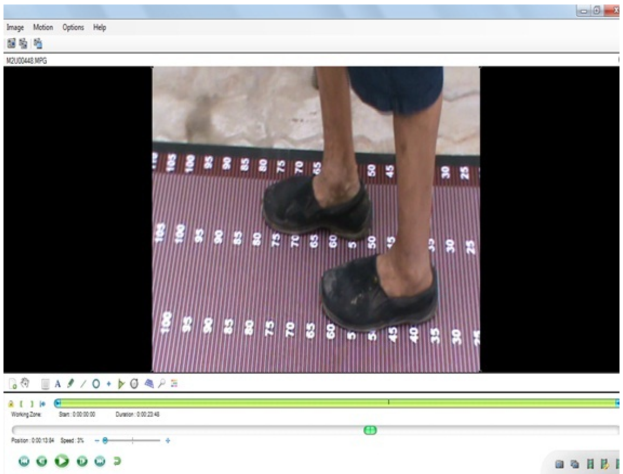
Figure 2: ***BalanceGrid***

Before the people with stroke were put to test on the BalanceGrid, normal subjects with no known neurological dysfunction were tested to check the applicability of the device. Further, people with stroke donned the waist belt and the LASER pointer and were asked to stand facing away from the height adjustable table. The distance of the feet from the table was adjusted first and then the height of the table was adjusted, once the subject stood on the paper foot mat. One of the investigators ensured the subject's safety by standing close and encouraged the subject to use ankle strategy only to the best of his/her ability and minimize hip strategy while estimating the excursion of the LASER point, a surrogate for center of pressure (CoP). Subjects were instructed to shift their weight forward -backward and sideways to estimate the excursion of the CoP in the sagittal and frontal planes, respectively. The excursion of CoP on the graph sheets was captured using a video camera maneuvered by the other investigator, ensuring a maximum tilt of up to 15 degrees to minimize the parallax error. The angle of the video camera was standardized using a bubble inclinometer, and adequate practice was allowed before the actual measurement was recorded. Later, the video was analyzed to identify the maximal deflection points of the LASER beam in both directions. The extreme deflection points were determined by the average of three frozen panes of the video clip using Kinovea motion analysis software (Manf: Kinovea). The anterior-posterior and lateral balance stability limits were determined in centimeters by counting the number of squares traversed by the LASER beam in either direction. Two therapists (rater 1 and rater 2) calculated the readings on two different occasions interspersed by a one-week interval.

Development of WalkMeter system:

The WalkMeter system, a tool designed to assess spatial-temporal gait parameters, consists of a 10-meter walkway (3mm thick sun board) graduated in centimeters, a motion video camera and motion picture analysis software. The feasibility of this system in capturing the parameters was tested on normal subjects before applying it on subjects with hemiplegia. The subjects were instructed to walk with their footwear on and at their normal walking speed. Two walking trails were recorded, and one of the videos was randomly picked up for analysis. Two raters analyzed the data at different time points within 5-7 days to minimize the recall bias. The video recording from the middle six meters only was considered for analysis to overcome confounding factors such as acceleration and deceleration, which were noted during the initial and later sections of the walkway, respectively. The tester stood alongside the subject and video recorded the movement sequence of walking in the sagittal plane. The movement video was analyzed using Kinovea software (Manf: Kinovea. Inc), which reads 25 frames per second with each frame lasting for 0.04 seconds. The spatial- temporal parameters were determined on the software as: Step length - distance between initial contacts of the uninvolved extremity to that of involved extremity. Stride length - distance between the initial contact of one foot to the point of next initial contact of the same foot. Single support time - time spent when one of the feet is in contact with the ground. Double support time- time frame when both feet are in contact with the ground. Gait speed - distance walked in a given time frame (Figure 3).

Figure 3: ***WalkMeter & Kinovea software***



Data Analysis:

Data was analyzed using SPSS version 16.0. The normality of the demographic characteristics was observed with Kolmogorov-Smirnov test. Pearson's correlation was built between the CoP excursion and spatial-temporal gait parameters data estimated at two different time frames. The reliability of the tools was reported through Cronbach's alpha (α) and intra-class correlation coefficient (r). Cronbach's alpha (α) was established to provide a measure of the internal consistency of the balance stability and gait variables, i.e., CoP excursion and spatial-temporal gait parameters, and is expressed as a number between 0 and 1 (Henson., 2001). An '*r*' value more than 0.8 indicates high reliability, the value of 0.4-0.8 indicates moderate reliability, and less than 0.4 indicates poor reliability (Weir, 2005). Standard error of measurement (SEM) was calculated to find the effect of measurement error on the observed values and was reported using the formula SEM= SD √1-r (Harvill, 1991).

Results

This study enrolled 40 healthy volunteers and 47 people post-stroke with a mean age of 50.31 and 55.73 years, respectively. Of the 47 people with stroke, 32 were males and 15 were females. Sixty two percent of them suffered from ischemic stroke and 38 % had a hemorrhagic stroke lesion. The mean post-stroke duration was 12 months, and 76 % of people were in late stage hemiplegia. Among the 47 people post stroke, 30 were walking independently and 17 were using mobility aids while walking. Their lower limb recovery stage was 3.62 (0.47) as per Brunnstrom's stroke recovery grading. The demographic characteristics of study participants are shown in Table 1.

Table 1: Demographic characteristics of people with stroke

Demographic Variables (N=47)	Mean (SD) / Number (%)
Age (Years)	55.73 (12.1)
Gender (Male/Female)	32 (68) / 15 (32)
Type of lesion (Ischemic/Hemorrhagic)	29 (62) / 18 (38)
Side of hemiplegia (Right/Left)	17 (36) / 30 (64)
Post stroke duration (Months)	12.06 (10.3)
Brunnstrom recovery stage (1-6)	3.62 (0.47)
Walk Ability (Independent/ Walking Aid)	30 (64) /17 (36)
Height (cm)	167.8 (9.6)
Weight (kg)	71.2 (9.6)
BMI (kg/m^2)	25.2 (3.2)

The '*r*' values from ICC demonstrated high intra-rater and inter-rater reliability for both clinical tools (0.82-0.99). Reliability of BalanceGrid and WalkMeter measures for healthy volunteers and people post stroke are shown in Tables 2 and 3.

Table 2: BalanceGrid measures and reliability in healthy individuals and people post stroke

Variables	Test	Healthy Volunteers (N=40)				People with Stroke (N=47)							
		Rater 1				Rater 1				Rater 2			
		Mean (SD)	*r* value	SEM	*p* value	Mean (SD)	*r* value	SEM	*p* value	Mean(SD)	*r* value	SEM	*p* value
Anterior-Posterior CoP Excursion (cm)	1 2	27.35 (3.3) 26.95 (3.5)	.954 (.92-.97)	0.60	<0.001	15.18 (5.4) 15.48 (5.2)	.973 (.95-.98)	0.90	<0.001	15.98 (5.5) 16.08 (5.4)	.94 (.89-.96)	1.29	<0.001
						* ICC: 0.82 (0.73-0.89); SEM: 2.26^							
Lateral CoP Excursion (cm)	1 2	42.60 (9.3) 41.82 (9.3)	.83 (.70-.91)	3.81	<0.001	19.7 (7.7) 19.7 (7.6)	.987 (.97-.99)	1.06	<0.001	19.45 (7.1) 19.65 (6.9)	.98 (.96-.98)	0.98	<0.001
						* ICC: 0.97 (0.96-0.98); SEM:1.19^							

** Inter rater reliability; ^ p value<0.001; CoP=Center of Pressure; ICC=Intraclass Correlation Coefficient; SEM=Standard Error of Measurement; p value <0.05 is statistically significant.*

Internal consistency reliability from Cronbach's alpha value for various balance and gait measures are as follows: Anterior-posterior CoP excursion (0.948- 0.986); lateral CoP excursion (0.989-0.995); Single support time of hemiplegic leg (0.866-0.976); Single support time of non-hemiplegic leg (0.932-0.985); Double support time (0.992-0.998); Step length of hemiplegic leg (0.984-0.989); Step length of non-hemiplegic leg (0.989-0.996); Stride length of hemiplegic leg

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(0.984-0.999) ; Stride length of non-hemiplegic leg (0.994-0.999); Gait speed (0.996-1) and Cadence (0.997-0.999) (Tables 2 & 3) .

Table 3: Spatial-temporal gait parameters and reliability of WalkMeter of participants

Variables	Test	Healthy Volunteers (N=40)				People with Stroke (N=47)							
		Rater 1				Rater 1				Rater 2			
		Mean (SD)	*r* value	SEM	*p* value	Mean (SD)	*r* value	SEM	*p* value	Mean (SD)	*r* value	SEM	*p* value
SSTD/ SSTH (seconds)	1 2	0.34 (0.08) 0.32 (0.12)	.987 (.97-.98)	0.02	<0.001	.35 (.1) .36 (.9)	.953 (.91-.97)	0.04	<0.001	0.35 (0.10) 0.36 (0.09)	.976 (.95-.98)	0.02	<0.001
						**r* value: .866 (.78-.92); SEM: .5^							
SSTND/ SSTNH (seconds)	1 2	0.33 (0.11) 0.34 (0.11)	.976 (.97-.98)	0.02	<0.001	.5 (.13) .51 (.12)	.969 (.94-.98)	0.02	<0.001	0.52 (0.13) 0.53 (0.14)	.873 (.77-.93)	0.05	<0.001
						**r* value: .928 (.87-.96); SEM: .4^							
DSTN/DSTH (seconds)	1 2	0.14 (0.04) 0.15 (0.08)	.978 (.97-.98)	0.01	<0.001	.5 (.35) .49 (.36)	.998 (.98-.99)	0.05	<0.001	0.51 (0.32) 0.52 (0.28)	.99 (.98-.99)	0.03	<0.001
						**r* value: .992 (.98-.99); SEM: .3^							
SLD /SLH (cm)	1 2	52.4 (7.2) 52.9 (7.6)	.988 (.98-.99)	1.04	<0.001	29.3 (1.9) 3 (11.1)	.975 (.95-.98)	1.54	<0.001	28.70 (13) 29.1(12.5)	.978 (.95-.98)	1.54	<0.001
						**r* value: .986 (.97-.99); SEM: 1.68^							
SLND/SLNH (cm)	1 2	53.4 (7.1) 53.2 (7.3)	.995 (.98-.99)	1.01	<0.001	27.72 (13.5) 27.7 (13.2)	.991 (.98-.99)	1.32	<0.001	26.9 (12.8) 27.6 (12.7)	.978 (.95-.98)	1.75	<0.001
						**r* value: .984 (.96-.98); SEM: 1.68^							
StLD/ StLH (cm)	1 2	105.7 (12.8) 104.9 (12.5)	.987 (.97-.99)	2.12	<0.001	56.6 (18.6) 56.7 (18.7)	.997 (.98-.99)	1.87	<0.001	55.8 (19.2) 56.4 (19.4)	.984 (.98-.99)	2.16	<0.001
						**r* value: .992 (.98-.99); SEM: 1.2^							
StLND/StLNH (cm)	1 2	105.6 (12.6) 105.2 (12.3)	.991 (.98-.99)	1.72	<0.001	57.9 (2.3) 57.1 (2.4)	.997 (.98-.99)	2.04	<0.001	57.2 (20.6) 57.6 (20.2)	.994 (.98-.99)	1.55	<0.001
						**r* value: .995 (.98-.99); SEM: 1.11^							
Speed (meter/second)	1 2	1.12 (0.93) 1.17 (0.89)	1	0	<0.001	.34 (.2) .33 (.21)	.996 (.98-.99)	0.01	<0.001	0.36 (0.24) 0.35 (0.20)	.996 (.98-.99)	0.01	<0.001
						**r* value: .976 (.95-.98); SEM: 1.64^							
Cadence (steps/minute)	1 2	118.4 (13.2) 118.1(13.5)	1	0	<0.001	73.9 (21.4) 73.9 (21.4)	1	0	<0.001	74.3 (21.7) 73.8 (21.4)	.994 (.98-.99)	1.62	<0.001
						**r* value: 0.996 (0.98-0.99); SEM: 1.26^							

**Inter-rater reliability;^ p value<0.001; ICC=interclass Correlation Coefficient; SEM=Standard Error of Measurement; p value<0.05 statistically significant; SSTD-single support time dominant leg; SSTH-single support time hemiplegic leg; SSTND-single support time non-dominant leg; SSTNH- single support time non-hemiplegic leg; DSTN- double support time (normal); DSTH- double support time (hemiplegia); SLD- step leg dominant leg; SLH- step length hemiplegic leg; SLNH- step length non-hemiplegic leg; SLND- step length non-dominant leg; StLD-stride length dominant leg; StLH-stride length hemiplegic leg; StLND-stride length non-dominant leg ; StLNH- stride length non-hemiplegic leg*

Discussion

We aimed to develop new clinical tools like BalanceGrid and WalkMeter in order to measure the limits of balance stability and gait parameters in people post stroke, and also to check their intra-rater and inter-rater reliability. This study showed high reliability for both BalanceGrid and WalkMeter measurements. To minimize the potential measurement error, the order of both balance and walking trials were determined using a coin toss method for every study participant. Furthermore, to minimize the memory recall bias, the rater-1 and rater-2 measured the second reading 5-7 days after the first reading from the recorded video.

We found a two-fold decrement in the CoP excursion during anterio-posterior (AP) and lateral weight shifts in people after stroke compared to healthy individuals. This could be due to the fact that people post stroke had difficulty in loading their weight towards the hemiplegic side and fear of losing balance. The standard error of measurement (SEM) for AP and lateral CoP ranged between 0.96-2.26 and 0.979-1.11, respectively. Standard error of measurement is usually related to test reliability, which is an indicator of the dispersion of the measurement errors, and it is used to estimate a band of values around any cut point (Harvill. 1991). The Cronbach's alpha value of 0.82-0.97 indicates that the BalanceGrid is capable of measuring the limits of balance stability following stroke and an alpha of 0.80 determines it to be good tool (Page and Garner, 2005). To the best of our knowledge, there are two clinically feasible methods, e.g., digital weighing scales and swaymeter, reported in the literature to measure standing limb loading and balance stability. Digital weighing scales may be capable of identifying asymmetrical standing limb loading in people post stroke but cannot measure the dynamic balance stability, which requires advanced laboratory balance tools such as force plates and posturography. The Swaymeter, a recently developed clinical tool to assess the balance stability by measuring the AP and lateral CoP excursion has moderate to good reliability (ICC 0.6 – 0.8), but its accuracy of measurement is limited with pen- paper friction (Sturnicks, et al., 2011). The BalanceGrid system, the clinical tool tested in this study, was developed to overcome the frictional interface and demonstrated a high intra-rater reliability with an ICC score of 0.82 -0.97.

Slow walking speed (Brandtser, et al., 1983; Wall and Turnbull, 1986) and asymmetrical spatial-temporal gait parameters (Chitralakshmi, et al., 2009; George, et al., 2005; Olrey, et al., 1994; Olrey, et al., 1996) are common after stroke. The paper- dye method (Karthikbabu, et al., 2011), a clinically feasible mode of measuring gait parameter, might affect the actual walking speed of an individual since the dye applied at on the sole of the feet results in the sense of sticky perception. The WalkMeter system with a walkway made out of 3 mm sun-board has properties similar to the floor surface, and it allows people after stroke to use their footwear while walking over the walkway. We also confirmed that there was a similar gait speed while walking over the floor surface and the WalkMeter walkway. The WalkMeter system with its software showed similar spatial-temporal gait parameters as those of the reference values given for the age group between 50 and 60 years using a gait laboratory (Oberg, et al., 1993; Goldie, et al., 2001). The internal consistency, interclass correlation coefficient and SEM values of spatial-temporal gait parameters post stroke reported in this study were 0.866-0.999, 0.866-0.999 and 0.01-2.16, respectively. Thus, the WalkMeter could be considered as a reliable tool and is economical and easy to administer in clinical practice. However, the authors recommend practitioners to be well-versed with the skills of motion video capture. Despite the benefits, both the BalanceGrid and WalkMeter systems require further standardization and need to be tested for their validity. In this regard, we recommend to check the validity of the BalanceGrid and WalkMeter systems comparing with gold standard tools such as force plate and GaitRite systems in future studies.

Conclusion

The BalanceGrid and WalkMeter systems allow measurement of the limits of balance stability and spatial-temporal gait parameters that is simple, easy to administer and cost effective than advanced balance and gait laboratory methods. As the BalanceGrid and WalkMeter systems have shown high internal consistency and test-retest reliability, they are recommended to screen and quantify the limits of balance stability and spatial-temporal gait parameters in people after stroke.

Conflict of interest: None declared

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