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Minimal detectable change for gait variables collected during treadmill walking in individuals post-stroke

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Abstract

Post-stroke gait impairments are common and result in slowed walking speeds and decreased community participation post-stroke. Treadmill training has recently emerged as an effective gait rehabilitation intervention. Furthermore, kinematic and kinetic data collected during treadmill walking are commonly used for assessing gait performance. The minimal detectable change (MDC) for gait variables provides a useful index to determine whether the magnitude of change in gait produced after an intervention is greater than the amount of change attributable to day-to-day variability in gait or test–retest measurement errors. The MDC values for kinematic, ground reaction force (GRF), spatial, and temporal variables collected during treadmill walking post-stroke have not been previously reported. The objective of this study was, therefore, to compute MDCs for post-stroke gait kinematics, GRF indices, temporal, and spatial measures during treadmill walking. Nineteen individuals with chronic post-stroke hemiparesis (12 males; age = 47–75 years; 72.6 ± 63.4 months since stroke) participated in 2 testing sessions separated by 20.7 ± 26.8 days. Our results showed that test–retest reliability was excellent for all gait variables tested (intraclass correlation coefficients = 0.799–0.986). MDCs were reported for hip, knee, and ankle joint angles (range 3.8° for trailing limb angles to 11.5° for hip extension), peak anterior GRF (2.85% body weight), mean vertical GRF (4.65% body weight), all temporal variables (range 3.2–4.2% gait cycle), and paretic step length (6.7 cm). These MDCs provide a useful reference to help interpret the magnitudes of changes in post-stroke gait variables.

Keywords

Hemiparesis; Stroke; Treadmill; Gait; Reliability; Minimal detectable change

1. Introduction

Treadmill training is commonly used for post-stroke gait rehabilitation [1–3]. To evaluate the efficacy of gait rehabilitation, it is critical to accurately measure post-stroke gait impairments before and after rehabilitation. Kinematic, ground reaction force (GRF), and spatiotemporal gait data provide a comprehensive assessment of gait deficits [4–7]. An estimate of typical variability in gait data with repeated testing is helpful in determining if observed changes in gait are due to the intervention being investigated or simply

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measurement errors due to test–retest or day-to-day gait variability. The minimal detectable change (MDC) [8,9] represents the amount of change in a variable necessary to conclude that the change is not attributable to error; it is the smallest change that falls outside the expected range of error and represents a “real” change [8,9].

The reliability of kinematic and spatiotemporal data [5] and MDCs for GRF data [6] during overground walking has been previously reported for individuals post-stroke. A limitation in these studies was that the test and retest were conducted on the same day and therefore, did not account for day-to-day gait variability [5,6]. Thus, application of these results when interpreting data from reports involving pre- and post-intervention testing is limited. Furthermore, despite the increasing use of treadmills for stroke rehabilitation [1–3] and for measuring gait [1,2,4,10], MDCs for gait variables obtained during treadmill walking post-stroke have not been previously reported. The objective of the current study, therefore, was to determine MDCs for kinematic, GRF, temporal, and spatial gait variables during treadmill walking using data from repeated testing sessions in individuals with post-stroke gait impairments.

2. Methods

Nineteen individuals (12 males; age 47–75 years) with post-stroke hemiparesis (72.6 ± 63.4 months post-stroke) able to walk for >5 min were recruited (Table 1). Exclusion criteria included inability to follow commands and orthopedic or other neurologic conditions interfering with walking. All subjects signed consents approved by the Human Subject Review Board. Each subject participated in 2 sessions conducted on separate days (20.7 ± 26.8 days between sessions), with identical testing procedures.

During gait analysis, subjects walked on a split-belt treadmill (AMTI, Watertown, MA) with two 6-degree of freedom force platforms. Subjects held a handrail and wore a harness without body weight support. Marker data collected at 100-Hz using an 8-camera motion analysis system (Vicon 5.2, Oxford, UK) were synchronized with GRF data sampled at 2000 Hz. The marker-set used during motion analysis is shown in Fig. 1. Two walking trials (20–40-s in duration) were collected as the subject walked at their self-selected speeds.

Marker trajectories and GRFs were low-pass filtered at 6 and 30 Hz, respectively (Visual 3D; C-Motion, MD). Vertical GRFs were used to identify gait events. For each subject, data from the first 9 usable consecutive strides were analyzed.

2.1. Dependent variables

Kinematic variables—(1) Peak ankle angle during swing, (2) ankle angle at initial contact, (3) peak knee flexion during swing, (4) hip extension at toe-off, and (5) trailing limb angle. *Trailing limb angle* was computed as the peak of the planar angle between the laboratory's vertical axis (along the sagittal plane) and a vector joining markers located on the lateral malleolus and the greater trochanter of the paretic lower extremity.

GRF variables—*Mean vertical GRF* during stance was computed as the integral of the vertical GRF between initial contact and toe-off divided by the stance duration. *Peak anterior GRF (AGRF)* was the peak of the positive (propulsive) phase of the anterior-posterior GRF between zero-crossing of the antero-posterior GRF and toe-off. *Push-off Integral* was the integral of the anterior component of the antero-posterior GRF between the point of zero crossing of the antero-posterior GRF and toe-off. *Percent Propulsion* was the ratio of the pushoff integral for the paretic versus the total for paretic and non-paretic legs [7,11].

Spatial variables—Step length was computed as the anteroposterior distance between markers placed on the heels of the leading versus the trailing limbs. Step symmetry was computed as the ratio between the paretic step length versus the sum of paretic and non-paretic step lengths [12]; step symmetry = 0.50 implies perfect symmetry.

Temporal variables—*Stance phase duration*, *swing phase duration*, and *single limb support duration* were determined, and normalized to stride duration. Double support (time between contralateral initial contact and ipsilateral toe-off) was computed during the terminal double support phase of gait.

2.2. Statistical analyses

MDC calculation—To determine *between-session reliability*, ICCs (3,1) were computed for agreement between data from session 1 versus 2 using a ‘two-way mixed model’ for absolute agreement (SPSS 16.0, Chicago, IL). Standard error of measurement (SEM) [6,8] was

$$\text{SEM} = \text{SD} \times \sqrt{1 - \text{ICC}} \quad (1)$$

where SD is the average of standard deviations for sessions 1 and 2.

The MDC was calculated as [6,8]:

$$\text{MDC} = \text{SEM} \times 1.962 \times \sqrt{2} \quad (2)$$

For each variable, *Bland–Altman plots* [13] were generated to assess the distribution of between-session errors.

For *within-session reliability*, values for each variable from the 1st session were compared across 9 consecutive strides and similar analyses to those described for between-session reliability above were performed. However, for within-session MDCs, ICCs assessed agreement across strides and SD was the standard deviation across 9 strides.

3. Results

We reported MDC values (see Table 2) and demonstrated excellent between-session (ICCs range from 0.799 to 0.986) and within-session reliability (ICCs ≥ 0.9) for kinematic, spatio-temporal, and GRF data collected during treadmill walking in individuals post-stroke. Bland–Altman plots showed no systematic trends in the direction or distribution of test–retest errors for majority of variables (Fig. 2).

4. Discussion

We reported MDCs for post-stroke gait variables obtained via three-dimensional motion capture during treadmill walking. The between-session MDCs from our study account for test–retest errors in gait variables across 2 testing sessions caused by factors such as recalibrating the camera system, re-attaching reflective markers, and day-to-day gait variability. Between-session MDCs estimate the minimum change in gait that must be produced by an intervention for the change to be considered real; they can therefore provide a reference for assessing the magnitude of changes produced by an intervention over the course of days or weeks. We also computed within-session MDCs using multiple gait strides

collected during a single session. As anticipated, within-session MDCs for all variables were smaller than the between-session MDCs (Table 2). The within-session MDCs can be used to estimate the magnitude of change representing a real change in studies investigating immediate effects of a perturbation to walking (e.g. change in speed, electrical stimulation).

Because MDC values are specific to the population and methods used, several aspects of our study should be highlighted for those interested in interpreting their data relative to the data presented. First, gait analysis was performed during treadmill walking. Due to its ease of use, ability to provide data for numerous strides, and systematically modulate walking speed, treadmill walking has gained popularity as an intervention [1–3] and as a tool for assessing gait performance [1,2,4,14]. However, these MDCs may not be used to interpret studies that measure overground gait. Second, the same experimenter, who demonstrated procedural reliability for data-collection and processing, applied markers at each gait analysis session. Ideally, similar stringent measures must be undertaken to ensure reliability of gait data. Third, our MDC values may not be applicable to post-stroke individuals who differ substantially from those recruited in this study, e.g. persons with acute or multiple strokes.

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References

1. Daly JJ, Roenigk K, Holcomb J, Rogers JM, Butler K, Gansen J, et al. A randomized controlled trial of functional neuromuscular stimulation in chronic stroke subjects. *Stroke* 2006;37:172–8. [PubMed: 16322492]
2. Macko RF, Ivey FM, Forrester LW, Hanley D, Sorkin JD, Katzell LI, et al. Treadmill exercise rehabilitation improves ambulatory function and cardiovascular fitness in patients with chronic stroke: a randomized, controlled trial. *Stroke* 2005;36:2206–11. [PubMed: 16151035]
3. Mulroy SJ, Klassen T, Gronley JK, Eberly VJ, Brown DA, Sullivan KJ. Gait parameters associated with responsiveness to treadmill training with body-weight support after stroke: an exploratory study. *Phys Ther* 2010;90:209–23. [PubMed: 20022996]
4. Kesar TM, Perumal R, Reisman DS, Jancosko A, Rudolph KS, Higginson JS, et al. Functional electrical stimulation of ankle plantarflexor and dorsiflexor muscles: effects on poststroke gait. *Stroke* 2009;40:3821–7. [PubMed: 19834018]
5. Yavuzer G, Oken O, Elhan A, Stam HJ. Repeatability of lower limb three-dimensional kinematics in patients with stroke. *Gait Post* 2008;27:31–5.
6. Campanini I, Merlo A. Reliability, smallest real difference and concurrent validity of indices computed from GRF components in gait of stroke patients. *Gait Post* 2009;30:127–31.
7. Bowden MG, Balasubramanian CK, Neptune RR, Kautz SA. Anterior-posterior ground reaction forces as a measure of paretic leg contribution in hemiparetic walking. *Stroke* 2006;37:872–6. [PubMed: 16456121]
8. Beckerman H, Roebroeck ME, Lankhorst GJ, Becher JG, Bezemer PD, Verbeek AL. Smallest real difference, a link between reproducibility and responsiveness. *Qual Life Res* 2001;10:571–8. [PubMed: 11822790]
9. Beaton DE, Bombardier C, Katz JN, Wright JG. A taxonomy for responsiveness. *J Clin Epidemiol* 2001;54:1204–17. [PubMed: 11750189]

10. Hidler J, Nichols D, Pelliccio M, Brady K, Campbell DD, Kahn JH, et al. Multi-center randomized clinical trial evaluating the effectiveness of the lokomat in subacute stroke. *Neurorehabil Neural Repair* 2009;23:5–13. [PubMed: 19109447]
11. Balasubramanian CK, Bowden MG, Neptune RR, Kautz SA. Relationship between step length asymmetry and walking performance in subjects with chronic hemiparesis. *Arch Phys Med Rehabil* 2007;88:43–9. [PubMed: 17207674]
12. Patterson KK, Gage WH, Brooks D, Black SE, McIlroy WE. Evaluation of gait symmetry after stroke: a comparison of current methods and recommendations for standardization. *Gait Post* 2010;31:241–6.
13. Bland JM, Altman DG. Comparing methods of measurement: why plotting difference against standard method is misleading. *Lancet* 1995;346:1085–7. [PubMed: 7564793]
14. Reisman DS, Wityk R, Silver K, Bastian AJ. Locomotor adaptation on a split-belt treadmill can improve walking symmetry post-stroke. *Brain* 2007;130:1861–72. [PubMed: 17405765]

Fig. 1.
Anatomical positioning of the retro-reflective markers used for motion analysis during data collection. Illustrated by Adam R. Marmon, PhD.

Fig. 2.

Bland–Altman plots for peak ankle during swing (A), % propulsion (B), paretic pushoff integrals (C), peak anterior GRF (AGRF) (D), hip angles at toe-off (E), and trailing limb angle (F). These figures plot the average value for each variable across the 2 testing sessions on the abscissa, and the error (difference between session 1 versus session 2) between the values for the 2 testing sessions on the mantissa. Data are shown for 19 subjects; each data point represents one subject.

Table 1

Subject characteristics.

Subject	Gender	Age (years)	Side of hemiparesis (L/R)	Time since stroke (months)	Gait speed (m/s)	Time between test-retest sessions (days)	Fugl-Meyer (LE) score
1	F	59	R	20.09	0.3	53	13
2	F	55	R		0.5	54	17
3	F	66	R	29.33	0.5	99	18
4	M	71	L	34.55	0.5	60	13
5	M	68	R	35.05	0.3	2	21
6	F	71	L	15.85	0.3	3	22
7	M	47	R	15.52	0.4	30	15
8	M	75	R	70.49	0.7	9	27
9	M	69	L	43.96	0.9	7	21
10	F	60	L	270.64	0.2	4	20
11	F	53	L	37.55	0.3	2	20
12	M	52	L	126.38	0.9	7	24
13	M	54	L	91.2	0.6	5	20
14	M	57	R	131.84	1.2	5	21
15	M	73	R	87.39	0.5	7	14
16	M	57	R	47.21	0.7	21	19
17	M	60	R	133.35	0.7	8	15
18	M	62	R	84.39	0.8	16	25
19	F	67	R	32.12	0.3	1	18
Mean		61.9		72.6	0.6	20.7	19.1
StDev		8.0		63.4	0.3	26.8	4.0

ICC, 95% confidence interval for the ICCs, and minimal detectable change (MDC) values for gait variables. Both between-session and within-session reliability data are reported.

Table 2

	Between session			Within session		
	ICC	95% CI for ICC	MDC	ICC	95% CI for ICC	MDC
Kinematic variables (°)						
Peak knee flexion during swing	0.982	0.955–0.993	5.7	0.998	0.996–0.999	1.9
Peak ankle angle during swing	0.941	0.849–0.977	4.9	0.998	0.996–0.999	0.9
Ankle angle at initial contact	0.893	0.729–0.959	7.0	0.994	0.988–0.997	1.6
Trailing limb angle	0.971	0.915–0.985	3.8	0.998	0.995–0.999	1.0
Hip angle at toe off	0.799	0.473–0.923	11.5	0.997	0.994–0.999	1.5
GRF variables						
Peak anterior GRF (% body wt)	0.945	0.820–0.980	2.85	0.996	0.993–0.998	0.80
Paretic push off integral (% body wts)	0.935	0.781–0.977	1.01	0.997	0.994–0.999	0.24
Non-paretic push-off integral (% body wt.s)	0.911	0.753–0.967	1.32	0.990	0.981–0.995	0.47
Mean vertical GRF (% body wt)	0.946	0.860–0.979	4.65	0.994	0.989–0.997	1.74
Percent propulsion (%)	0.943	0.849–0.978	12.06	0.994	0.990–0.997	3.92
Spatial variables						
Paretic step length (cm)	0.970	0.924–0.988	6.75	0.996	0.992–0.998	2.62
Nonparetic step length (cm)	0.986	0.963–0.995	5.46	0.998	0.996–0.999	2.11
Step symmetry (ratio)	0.956	0.883–0.983	0.068	0.991	0.984–0.996	0.032
Temporal variables (% gait cycle)						
Paretic swing/nonparetic SLS	0.939	0.845–0.977	3.6%	0.983	0.968–0.992	2.0%
Paretic stance	0.939	0.845–0.977	3.6%	0.983	0.968–0.992	2.0%
Paretic double support	0.895	0.726–0.96	4.2%	0.979	0.962–0.991	2.0%
Paretic SLS/nonparetic swing	0.963	0.905–0.986	3.2%	0.995	0.991–0.998	1.2%
Nonparetic stance	0.963	0.906–0.986	3.2%	0.995	0.991–0.998	1.2%