J Rehabil Med 2017; 49: 322–326

ORIGINAL REPORT

LOWER-LIMB MOTOR COORDINATION IS SIGNIFICANTLY IMPAIRED IN AMBULATORY PEOPLE WITH CHRONIC STROKE: A CROSS-SECTIONAL STUDY

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Objectives: **To establish the deficits of motor coordination of the lower limbs after stroke, in comparison with healthy controls, and to investigate whether the magnitude of the deficits would be influenced by the levels of motor recovery.**

Design: **Cross-sectional study.**

Subjects: **Chronic stroke patients and healthy subjects.**

Methods: **Lower-limb motor coordination of both stroke and healthy volunteers was measured using the Lower Extremity Motor Coordination Test (LEMOCOT). The motor coordination deficits of the participants with stroke were analysed all together and separated, according to their levels of motor recovery, measured using the Fugl-Meyer lower-limb motor section scores.**

Results: **Ninety-seven individuals with chronic stroke, 55 men, mean age 58 years, were evaluated. Motor coordination was significantly impaired on both paretic (mean: −22 touches; 95% confidence interval (95% CI) −24 to −19; deficit: 61%) and non-paretic (mean −6 touches; 95% CI −8 to −4; deficit: 17%) lower limbs. Significant differences in the LEMOCOT scores were found between the levels of motor recovery ($p < 0.01$), except between the participants with marked and moderate impairments.**

Conclusion: **Motor coordination of the lower limbs is significantly impaired after stroke, but the deficits of the non-paretic lower limb (17%) appear not to be clinically relevant. These findings suggest that interventions prescribed to improve motor coordination after stroke should focus on the paretic lower limb and/or include bilateral activities.**

Key words: stroke; rehabilitation; motor skills; lower extremity.

Accepted Jan 25, 2017; Epub ahead of print Mar 29, 2017

J Rehabil Med 2017; 49: 322–326

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Stroke is the leading cause of adult disability worldwide (1). It is well known that the negative motor impairments following upper motor neurone damage, i.e. loss of strength and motor coordination, contribute most to such disabilities (2). Motor coordination refers to the ability to perform a motor task in an accurate, rapid, and controlled manner (3). Appropriate motor coordination of the lower limbs is important for the performance of activities of daily living, such as walking and turning (2). Likewise, motor coordination is related to more complex activities, such as household chores, shopping, leisure, and social outings, which are essential for full participation in the community (4, 5). If motor coordination is impaired after stroke, community activities may be limited and people may become housebound and isolated from society (6). Therapeutic interventions aiming at improving lower limb motor coordination, in addition to those to increase muscle strength, could be implemented if motor coordination is significantly impaired after stroke. However, despite the clinical importance of this impairment, there is limited information about the extent of loss of motor coordination after stroke of both paretic and non-paretic lower limbs.

A previous systematic review indicated that the Lower Extremity Motor Coordination Test (LEMOCOT) appeared to be the most suitable test to examine lower-limb motor coordination, since it showed appropriate levels of reliability, construct validity, and good clinical utility (7). A recent study demonstrated that the LEMOCOT showed appropriate measurement properties, i.e. intra-, inter-rater, and test-retest reliabilities, and standard error of measurement in people after stroke, and could be used for research and clinical purposes (8). Two previous studies measured motor coordination of the lower limbs in a large sample of people after stroke using the LEMOCOT. The results indicated that the mean score of the paretic lower limb ranged between 8 and 12 (9, 10), which is ~30% of the predicted values for healthy individuals (11). However, these studies did not compare the results with healthy individuals and only provided information regarding the paretic lower limb.

Data from the non-paretic side of individuals with stroke are often considered as references for clinicians and researchers, because it is assumed that it has no deficits (12). However, previous studies reported that the strength deficit of the non-paretic side was approximately 25% of that of healthy controls (13, 14). Although one may argue that the magnitude of the weakness of the non-paretic side is not clinically worthwhile, the

doi: 10.2340/16501977-2215

non-paretic side may still not be considered unimpaired and might not be used as a reference. In addition, deficits in manual dexterity, motor coordination, and kinaesthesia of the non-paretic upper limb have also been demonstrated (12). Therefore, an investigation of loss of lower-limb motor coordination after stroke, including an evaluation of the non-paretic lower limb and a comparison with matched healthy controls, is warranted.

Furthermore, historically, heterogeneous groups of people after stroke have been characterized and analysed all together. More recently, sub-group analyses demonstrated that people with stroke act differently, according to their levels of motor function, and this type of analysis is providing more useful information to clinicians (15–17). A recent study, which investigated the predictors of lower-limb motor coordination in people with stroke, indicated that motor recovery alone explained 50% of the LEMOCOT scores (18). Thus, it becomes important to report not only the overall lower-limb motor coordination scores, but also to take into account the participants' levels of motor recovery. This could help clinicians to target interventions to those who will most benefit.

The aim of the present study was therefore to quantify the extent of loss of motor coordination of both lower limbs in people with chronic stroke, in comparison with healthy individuals, matched by age and sex. The specific research questions were: What are the motor coordination deficits of the paretic and non-paretic lower limbs in ambulatory people with stroke? Is the magnitude of the deficits influenced by the participant's motor recovery levels?

METHODS

Participants

For this cross-sectional study, community-dwelling people with stroke were recruited from the general community of Belo Horizonte, Brazil, by means of advertisements and by screening out-patient clinics in public hospitals. This was a secondary analysis of a previous study aimed at investigating the potential predictors of lower-extremity impairments in motor coordination of stroke survivors (18). Subjects were included if they were ≥ 20 years of age; were at least 6 months after the onset of stroke; had weakness of the lower-limb muscles, as determined by 15% strength difference between the paretic and non-paretic limbs (19), and/or increased tonus of the paretic ankle plantar flexor muscles, as determined by scores different from zero on the Modified Ashworth Scale (MAS) (20); and had no cognitive impairments, as determined by the following education-adjusted cut-off scores on the Mini-Mental State Examination: 18/19 for the individuals with illiteracy and 24/25 for those with basic education (21). To establish the deficits of motor coordination of the lower limbs after stroke, data for 97 age- and sex-matched healthy controls were collected.

Measures of motor coordination were collected on one day in a research laboratory setting. The LEMOCOT scores of both paretic and non-paretic lower limbs of the participants with stroke were compared with those of healthy participants, matched by age and sex.

Procedures

Before data collection, eligible participants were informed about the objectives of the study and provided written consent, based on previous approval from the university ethics review board (# CAAE 06609312.0.0000.5149). All data were collected by well-trained physical therapists. Initially, demographic and clinical data were obtained by interviews. For characterization purposes, comfortable walking speed of the stroke participants was measured using the 10-m walking test (22), which yields strong inter-rater and test-retest reliabilities in people with stroke (23).

Motor coordination was measured with the LEMOCOT and reported as the number of targets touched (8). Participants performed the test with the paretic and non-paretic lower limbs, while seated on an adjustable chair, with their back supported, hands on their thighs, feet resting flat on a thin piece of rigid foam, heels on the proximal target, and knees at 90° flexion (Fig. 1). Then, after a familiarization trial, they were instructed to alternately touch the proximal and distal targets placed 30 cm apart with their big toe, for 20 s. The number of touched targets was counted and registered for analyses (9). Patients were instructed not to sacrifice the accuracy of the touches, nor the quality of the movement, to increase speed.

Motor recovery of the paretic lower limb was measured with the Fugl-Meyer lower-limb motor section scores. The Fugl-Meyer is a valid and reliable measure of motor recovery and is one of the most widely used instruments in clinical assessments (24, 25). A 3-point ordinal scale is applied for each item, where "zero" is given to a task that cannot be carried-out, "1" when the task is partially performed, and "2" for tasks that can be completely performed (26). Scores between 29 and 34 indicate mild impairments; 23–28, moderate impairments; 18–22 marked impairments; and ≤ 17 severe impairments (27). These cut-off values were decided prior to data analysis (28) and were used to categorize the participants as mildly, moderately, markedly and severely impaired.

Data analysis

Descriptive statistics and tests for normality (Kolmogorov-Smirnov) were calculated for all variables. For the control group, the LEMOCOT scores were averaged to provide a single value of motor coordination for both the dominant and non-dominant lower limbs (13, 14). The mean between-group differences (MD) and 95% confidence intervals (95% CIs) for both the paretic and non-paretic lower limbs were calculated for all participants analysed all together, and separately, according

Fig. 1. Subject performing the lower extremity motor coordination test.

to their levels of motor impairments. This type of analysis was chosen because, whereas the null hypothesis significance tests use probability levels (e.g. $p<0.05$) to evaluate the results of studies, effect size analyses (mean differences) focus on the magnitude of the differences between the groups or contrasting conditions to report and interpret the study results. Mean differences along with confidence intervals, while also functioning as hypothesis tests, provide additional information regarding the variability of an observed sample (i.e. its precision) and its probable relationships with the value of this statistic in the population from which the sample was drawn (i.e. its accuracy). Thus, it focuses attention on the magnitude and probability of an effect. This type of description assists in determining the clinical interpretation and importance of the observed differences, as well as the statistical significance of the findings (29).

In addition, one-way analysis of variance (ANOVAs), followed by Tukey *post-hoc* tests, were used to investigate differences in the LEMOCOT scores between the levels of motor impairments. Motor coordination deficits were calculated using the scores of the control group as references, as follows: Deficit = 100 – (stroke/control * 100) and reported for all levels of motor recovery. All analyses were performed with the SPSS statistical software 17.0 for Windows with a significance level of 5%.

RESULTS

Participant's characteristics

A total of 194 participants (97 individuals with stroke and 97 controls) comprised the sample. From a list of 485 individuals with stroke, 120 agreed to participate and were physically screened, but 23 did not meet the inclusion criteria. Thus, 97 participants with stroke, 55 men, with a mean age of 58 ± 12 years and a mean time since the onset of the stroke of 5 ± 5 years, were evaluated. The control group comprised 97 participants, matched by age and gender, who had a mean LEMOCOT score of 36 ± 7. Their descriptive data are summarized in Table I.

Motor coordination deficits of the paretic and non-paretic lower limbs

Extent of the motor coordination deficits of the paretic lower limb. The mean LEMOCOT scores of the paretic lower limb for all levels of motor recovery, as well as the differences between the stroke and the control groups are shown in Table II. Overall, motor coordination of the paretic lower limb of the stroke participants was significantly impaired, compared with that of the control group (MD: –22 touches; 95% CI –24 to –19). This indicated that motor coordination deficit of the paretic lower limb was 61%, compared with the data for the control participants. In addition, significant differences were found for the LEMOCOT scores of the paretic lower limb amongst the levels of motor recovery ($p<0.01$), except between the participants with marked and moderate impairments. The percentages of motor coordination deficits of the paretic lower limb were 89% for the participants with severe impairments, 75% for those with marked impairments, 64% for those with moderate impairments, and 36% for those with mild impairments.

Extent of motor coordination deficits of the non-paretic lower limb. The mean LEMOCOT scores of the non-paretic lower limb for all levels of motor recovery, as well as the differences between the stroke and the control groups are given in Table II. Overall, motor coordination of the non-paretic lower limb of the stroke participants was significantly impaired, compared with that of the control group (MD: –6 touches; 95% CI –8 to –4). This indicated that motor coordination deficit of the non-paretic lower limb was 17%, compared with the control participants. No significant differences were found for the LEMOCOT scores of the non-paretic lower limb, when the levels of motor recovery were

Table I. Participants' characteristics

	Stroke group with different levels of motor recovery					
Characteristics	Total (97)	Severe ($n=17$)	Marked ($n=16$)	Moderate ($n=30$)	Mild ($n=34$)	Control group ($n=97$)
Sex, men, *n* (%)	55 (57)	11 (65)	10 (63)	17 (57)	17 (50)	55 (57)
Age, years, mean (SD)	58 (12)	55 (10)	55 (16)	61(12)	59 (11)	58 (12)
Body mass, kg, mean (SD)	70 (17)	78 (11)	73 (15)	69 (20)	66 (17)	66 (10)
Body height, m, mean (SD)	1.58 (0.32)	1.64 (0.08)	1.62 (0.09)	1.59 (0.35)	1.52 (0.42)	1.61 (0.22)
Time since stroke, years, mean (SD)	5 (5)	5 (5)	6 (7)	4 (4)	5 (5)	NA
Paretic side, right, *n* (%)	46 (47)	9 (53)	4 (25)	17 (57)	16 (47)	NA
Tonus of the plantar flexor muscles, MAS scores (0–4), *n*						
0	34	5	2	6	21	NA
1	22	4	4	6	8	NA
1+	17	2	2	8	5	NA
2	16	4	5	7	0	NA
3	5	1	2	2	0	NA
4	3	1	1	1	0	NA
Fugl-Meyer scores (0–34), median (IQR)	26 (11)	14 (4)	20 (2)	26 (3)	32 (3)	NA
Walking speed (m/s), mean (SD)	0.72 (0.32)	0.70 (0.35)	0.88 (0.39)	0.82 (0.37)	1.22 (0.38)	–

SD: standard deviation; MAS: Modified Ashworth Scale; NA: not applicable; IQR: interquartile range.

Table II. Lower Extremity Motor Coordination Test (LEMOCOT) scores of the paretic lower limb and non-paretic limb of the stroke and age and sex-matched control group, according to the levels of motor recovery, mean differences between the stroke and controls, and motor coordination deficits of the non-paretic lower limb

Level of motor recovery	LEMOCOT scores Stroke group ($n=97$) Mean (SD)	LEMOCOT scores Control group ($n=97$) Mean (SD)	Between-group differences Stroke minus control Mean (SD) (95% CI)	Motor coordination deficit*
Paretic limb				
Severe	4 (6)	38 (7)	−34 (−38 to −30)	89
Marked	9 (9)	37 (5)	−28 (−32 to −24)	76
Moderate	13 (9)	36 (7)	−23 (−26 to −20)	64
Mild	23 (7)	35 (7)	−12 (−15 to −9)	34
Total	14 (11)	36 (7)	−22 (−24 to −19)	61
Non-paretic limb				
Severe	28 (7)	39 (6)	−11 (−15 to −7)	28
Marked	31(11)	39 (5)	−8 (−12 to −4)	20
Moderate	29 (10)	37 (7)	−8 (−11 to −5)	22
Mild	31 (9)	35 (7)	−4 (−7 to −1)	11
Total	30 (9)	37 (7)	−7 (−9 to −5)	19

*Motor coordination deficit = 100 − (stroke/control*100).
SD: standard deviation; CI: confidence interval.

considered. The percentages of motor coordination deficits of the non-paretic lower limb were 22% for the participants with severe impairments, 14% for those with marked impairments, 19% for those with moderate impairments, and 14% for those with mild impairments.

DISCUSSION

This study aimed at investigating motor coordination deficits of the paretic and non-paretic lower limbs in ambulatory people with chronic stroke. The results revealed that, compared with age- and sex-matched healthy controls, the deficits of the paretic and non-paretic lower limbs were 61% and 17%, respectively. Furthermore, the extent of the deficits of the paretic lower limb was different, according to the participants' motor recovery levels.

For the paretic lower limb, similar scores were reported by 4 other studies, which provided data regarding motor coordination, measured with the LEMOCOT (8, 9, 30, 31). The mean value of touched targets, which ranged between 8 and 14 in these studies, is similar to the results of the present study. However, the present findings strengthen the evidence of previous reported results, because they were based on a larger sample ($n=97$) and the scores of the stroke subjects were compared with those of age- and sex-matched healthy controls. The magnitude of the motor coordination deficit (61%) found in the present study was also similar to that reported for loss of strength (52–58%) (12, 13) after stroke. Clinically, these results suggest that therapeutic interventions aiming at improving motor coordination of the lower limbs should also be implemented in clinical practice.

Furthermore, this study investigated whether the magnitude of the motor coordination deficits was influenced by the participant's motor recovery levels. Interestingly, although the statistical analysis revealed significant differences in motor coordination between the 4 levels of motor recovery, even the participants with mild impairments demonstrated clinically relevant deficits of the paretic lower limb (36%). These results suggest that motor coordination of the paretic lower limb in ambulatory people with stroke should be evaluated and rehabilitated, regardless of the levels of motor recovery.

For the non-paretic lower limb, similar scores were reported by 2 other studies, which provided data regarding motor coordination, also measured using the LEMOCOT (8, 30). The mean touched targets, which ranged between 30 and 32 in the previous studies, is also similar to that found in the present study. However, although motor coordination deficit of the non-paretic lower limb was statistically significant, it represents less than half of that of the paretic limb. A mean deficit of 17% does not appear to be large enough to be clinically relevant, and the results suggest that interventions aimed at improving lower-limb motor coordination should focus on the paretic lower limb and/or bilateral activities. According to Dorsch et al. (14), those minor impairments observed on the non-paretic side of chronic stroke individuals may be related to the impact of the disuse, following by reduced physical activity levels after stroke.

The present study adds to knowledge regarding motor coordination impairments after stroke, by providing a comprehensive set of values for the stroke population. This study is the first to measure motor coordination in a larger sample of stroke individuals and compare the results with data of healthy controls, matched by age and sex. Furthermore, the present sample size covered a wide range of disability, with walking speeds ranging from 0.09 to 2.09 m/s. In addition, the advantage of measuring motor coordination at the chronic stages, i.e. more than 6 months after the onset of stroke, is that the impairments are representative of a long-term outcome and provide insight into what may need to be targeted during rehabilitation.

Study limitations

The sample was not randomly selected and may not, therefore, be fully representative of the stroke population. Since the recruitment was conducted on a volun-

teer basis, those volunteers who agreed to participate may differ from those of the general community.

Conclusion

The results of the present study indicated that motor coordination of the paretic lower limb is significantly impaired after stroke, regardless of the individuals' levels of motor recovery. Otherwise, the results also indicated that the motor coordination deficit of the non-paretic lower limb may not be clinically relevant. The findings suggest that interventions prescribed to improve motor coordination after stroke should focus on the paretic lower limb and/or be comprised of bilateral activities.

ACKNOWLEDGEMENTS

This research was supported by the Pró-Reitoria de Pesquisa da Universidade Federal de Minas Gerais and the Brazilian National Funding Agencies: CNPq [grant number 304434/2014-0] and FAPEMIG [grant number 00006-14].

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