Clin Rehabil OnlineFirst, published on November 11, 2009 as doi:10.1177/0269215509342335

Clinical Rehabilitation

# Hip abductor control in walking following stroke – the immediate effect of canes, taping and TheraTogs on gait

**Clare Maguire** Bildungszentrum Gesundheit Basel Stadt, Studiengang Physiotherapie, Munchenstein, Switzerland, **Judith M Sieben** Department of Anatomy, Faculty of Health, Medicine and Life Sciences, Maastricht University, The Netherlands, **Matthias Frank** Department of Neurological Rehabilitation, Felix Platter Hospital, Basel and **Jacqueline Romkes** Laboratory for Movement Analysis, University Children's Hospital, Basel, Switzerland

Received 2nd March 2009; returned for revisions 25th May 2009; revised manuscript accepted 16th June 2009.

**Objective**: To confirm previous findings that hip abductor activity measured by electromyography (EMG) on the side contralateral to cane use is reduced during walking in stroke patients. To assess whether an orthosis (TheraTogs) or hip abductor taping increase hemiplegic hip abductor activity compared with activity during cane walking or while walking without aids. To investigate the effect of each condition on temporo-spatial gait parameters.
**Design**: Randomized, within-participant experimental study.
**Setting**: Gait laboratory.
**Subjects**: Thirteen patients following first unilateral stroke.
**Intervention**: Data collection over six gait cycles as subjects walked at self-selected speed during: baseline (without aids) and in randomized order with (1) hip abductor taping, (2) TheraTogs, (3) cane in non-hemiplegic hand.
**Main measures**: Peak EMG of gluteus medius and tensor fascia lata and temporo-spatial gait parameters.
**Results**: Cane use reduced EMG activity in gluteus medius from baseline by 21.86%. TheraTogs increased it by 16.47% (change cane use–TheraTogs $P = 0.001$, effect size = –0.5) and tape by 5.8% (change cane use–tape $P = 0.001$, effect size = –0.46). In tensor fascia lata cane use reduced EMG activity from baseline by 19.14%. TheraTogs also reduced EMG activity from baseline by 1.10% (change cane use–TheraTogs $P = 0.009$, effect size –0.37) and tape by 3% (not significant). Gait speed (m/s) at: baseline 0.44, cane use 0.45, tape 0.48, TheraTogs 0.49.
**Conclusion:** Hip abductor taping and TheraTogs increase hemiplegic hip abductor activity and gait speed during walking compared with baseline and cane use.

## Introduction

Regaining the ability to walk independently is an important aim of patients and therapists in stroke rehabilitation. Canes are commonly provided during the early stages of rehabilitation to enable

Address for correspondence: Clare Maguire, Bildungszentrum Gesundheit Basel Stadt, Studiengang Physiotherapie FH, Binningerstrasse 2, Munchenstein 4142, Switzerland.
e-mail: clare.maguire @bzgbs.ch


10.1177/0269215509342335

independent walking, although studies have consistently shown a significant reduction in surface electromyography (EMG) activity in all muscle groups on the side contralateral to cane use in both stroke and non-stroke patients.[1–4] Early walking is an important aim of stroke rehabilitation for many reasons, including the psychological well-being of the patient, to prevent loss of cardiovascular fitness, the development of secondary muscle weakness or further deterioration of abnormal muscle tone.

This study questions whether canes are the optimal walking aid to enable early independent walking as their use inhibits rather than stimulates activity of the hemiplegic musculature, contrary to the aims of rehabilitation.

On the positive side, canes have been shown to improve standing balance in patients with stroke by increasing the base of support.[5,6] Positive improvements in temporo-spatial gait parameters have also been recorded.[7] Cane use provided increased stability during the single limb support phase of the hemiplegic limb, allowing more time for the contralateral (non-hemiplegic) swing phase. This resulted in increased stride period and stride length of the non-paretic limb and reduced temporal asymmetry.

The authors hypothesize, however, that in the light of recent theories of motor learning, once the goal of improved stability in standing and walking is achieved through cane use, the imperative to recover inherent balance mechanisms may be reduced.[8–10] Reduced balance is closely associated with low ambulatory level in community-dwelling chronic stroke patients and may be an important factor in loss of cardiovascular fitness.[11] If the recovery of independent balance is adversely affected by cane use, there may be long-term consequences for the level of independence reached and for the cost of long-term care for stroke patients.

To date, no studies have investigated alternatives to cane use which enable early independent walking without reducing muscle activity or providing external balance support.

This study aimed to investigate the immediate effect of two alternatives – TheraTogs (an elasticized orthotic garment and strapping system) and hip abductor taping – on the activity of the hemiplegic hip abductor musculature, specifically gluteus medius and tensor fascia lata, as measured by surface EMG in patients recovering from first ever stroke. The level of activity was compared to EMG activity measured when walking without walking aids (baseline) and when walking with a cane. The immediate effect of each intervention on temporo-spatial gait parameters was also assessed.

The hip abductor musculature was investigated because improved postural control at the hemiplegic hip including hip abductor muscle control is an important element in restoring independent gait and balance.[12–14] It has also been shown that cane use in the contralateral hand reduces the mean hip abductor EMG by 31%. This can increase to a reduction of 42% when maximum push is applied to the cane.[3]

It was hypothesized that EMG activity would be reduced during cane walking compared with walking without aids and that EMG activity would be increased during walking with TheraTogs and tape compared with walking without aids.

It was also hypothesized that temporo-spatial gait parameters would improve during cane walking compared with walking without aids and that values during TheraTogs and tape walking would also improve but less than during cane walking.

## Methods

Following approval from the Ethics Committee of Basel a randomized, within-subject experimental study design was used.

Thirteen patients with hemiplegia following a first unilateral stroke were recruited from the Neurological Rehabilitation Department of the Felix-Platter Hospital in Basle, Switzerland. All patients scored at least level 3 on the Functional Ambulation Category[15] (able to walk unaided on even ground for at least 10 m but requiring verbal prompts and stand-by help without body contact). All patients were independent walkers prior to insult, had a Mini Mental State[16] score of 22 or above and had no orthopaedic or other neurological conditions that could limit walking ability. Patients had no gross visuospatial or visual field deficits and had no medical contraindications to walking.

At baseline, descriptive variables for each patient, including height and weight, were recorded.

Hip abductor muscle strength on the hemiplegic and non-hemiplegic sides was recorded while lying in a supine position using a hand-held dynamometer[17] (C.I.T. Technics BV, Haren/Groningen, The Netherlands).

Skin was then prepared for surface EMG placement. The skin was shaved over the gluteus medius and tensor fascia lata muscles and rigorously cleaned with alcohol. Surface EMG electrodes were placed onto the skin overlying these muscles following the 'European Recommendations for Surface Electromyography''(SENIAM) guidelines.[18] The ground electrode was placed on the clean-shaven skin over the sacrum. Bipolar Ag/AgCl surface electrode pairs with an electrode diameter of 10 mm and an inter-electrode spacing of 22 mm were used. Using a Neurodata system (Vienna, Austria; amplifiers of Biovison, Wehrheim, Germany) at a sampling rate of 2520 Hz, EMG signals were pre-amplified and band-pass filtered (10–700 Hz).

Skin impedance between the electrodes was measured with a skin impedance monitor (Grass Electrode Impedance Meter, Astro-Med, Inc, W.Warwick, RI, USA). An impedance range of 1–10 kohm was considered acceptable.[19]

Gait parameters were assessed using a six-camera, 120 Hz VICON 460 motion measurement system (Oxford Metrics Ltd, Oxford, UK). Fourteen-millimeter-diameter sphere-shaped reflective markers were affixed with double-sided tape bilaterally to the calcaneus, lateral malleolus, second metatarsal head and lateral surface of the lower leg below the head of the fibula. Infrared-sensitive solid-state cameras were used within this system for locating and following the fixed reflective markers through space.

Patients were asked to walk at a self-selected speed over an indoor, hard surface 10-m walkway without walking aids in their own footwear and with usual foot-ankle orthoses. Patients were accompanied by an assistant at all times who remained within arms' reach to ensure safety.

EMG and temporo-spatial parameters were collected to establish pre-experimental baseline values while walking without aids until six gait cycles with clear data-sets were collected. A gait cycle was defined as starting with initial foot contact and ending with the subsequent foot contact of the same leg.

Testing of the remaining three conditions then continued in a randomized order determined by a computerized randomization program while walking with (2) hip abductor taping, (3) TheraTogs, (4) cane with cane at normal height (defined as at the level of the radial styloid of the sound wrist) – at the Movement Analysis Laboratory, Basel, Switzerland.

Taping was applied to the hemiplegic side with the patient standing with the hip in 5 degrees abduction. Three bands of taping were applied from just below the greater trochanter (1) directly upwards to the iliac crest, (2) upwards and anteriorally to the anterior superior iliac spine, (3) upwards and posteriorally towards the posterior third of the iliac crest.

The TheraTogs consisted of two wide straps which were applied under tension over a hip held in 5 degrees abduction in standing, spanning the thigh cuff, crossing over the hip joint and attaching to the torso above the iliac crest.

All conditions are depicted in Figure 1.

**Primary outcome measure**

Percentage change of peak EMG in millivolts from baseline while walking with cane, TheraTogs and tape for gluteus medius and tensor fascia lata.

**Secondary outcome measures**

Temporo-spatial gait parameters at baseline and during interventions:

- self-selected walking speed in m/s,
- spatial asymmetry – calculated as step length asymmetry ratio (defined as non-paretic step length (m)/paretic step length (m)), and
- temporal asymmetry – calculated as mean single limb support time ratio (defined as mean non-paretic single limb support time (s)/ mean paretic single limb support time (s)).

These measures have been shown to correlate with balance and degree of motor function of the lower extremities following stroke.[20,21]

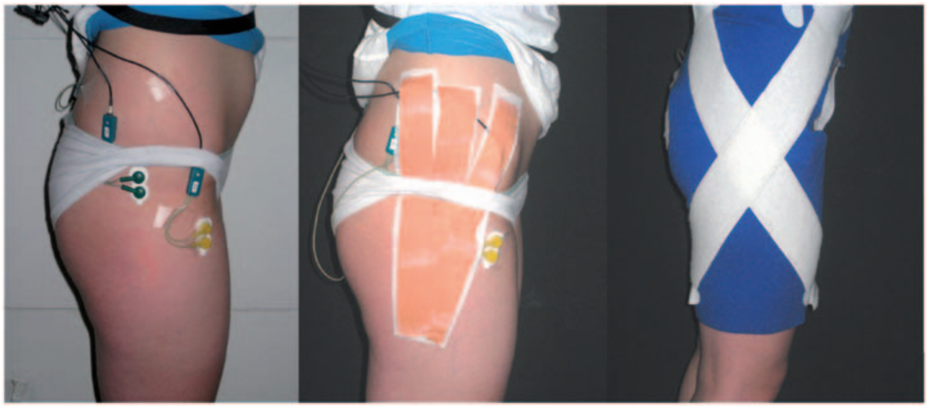

**Figure 1** Surface electrode positions, hip abductor taping technique and TheraTogs application.

The EMG signals were full-wave rectified and each data-set of one gait cycle was interpolated to 300 data-points using the MATLAB software package. For each subject the mean of each data-point from six gait cycles was calculated for each condition separately (baseline and interventions) and for each muscle (gluteus medius and tensor fascia lata). The peak EMG amplitude during baseline and interventions for each muscle was then identified. The EMG values obtained were then compared as a percentage change from baseline.

Friedman's ANOVA was used for non-parametric repeated measures analysis of variance to test for statistically significant differences in percentage change of peak EMG values between interventions, baseline and cane use. Wilcoxon tests were used as post-hoc tests to follow-up these findings and a Bonferroni correction was applied. All effects are therefore reported at a 0.0167 level of significance.

Friedman's ANOVA was also used to test for significant differences between changes in gait speed.

## Results

Thirteen subjects with hemiplegia following a first unilateral stroke were recruited. Five of the subjects were women and six had a right-sided hemiplegia. Mean age was 64 (standard deviation 14). Twelve of the 13 patients had just reached the point in their rehabilitation where they were to be provided with a cane or rollator frame to enable independent walking. The mean time since stroke for these patients was 9.2 weeks (range 5–16 weeks, standard deviation 3.8 weeks). These patients were able to walk short distances independently (minimum 10 m) but all required stand by assistance for safety when walking without aids. Three subjects wore ankle-foot orthoses due to inadequate dorsiflexion for foot clearance. One subject had a more chronic stroke (64 weeks since stroke) was independently mobile with a cane, and could walk on even surfaces independently without aids for approx. 30 m.

EMG data for each muscle and each condition was processed and graphically represented as in Figure 2.

EMG data collected and temporo-spatial gait parameters are presented in Table 1.

Friedman's ANOVA showed statistically significant differences between baseline and interventions for gluteus medius (chi-square (2) $=19.077$, $P<0.001$) and tensor fascia lata (chi-square (2) $=7.538$, $P=0.025$).

Cane use reduced EMG activity for gluteus medius from baseline by 21.86% whereas TheraTogs increased EMG activity for gluteus medius from baseline by 16.47%. This represented a highly statistically significant difference for change in peak EMG between cane use and TheraTogs for gluteus medius ($P<0.001$).

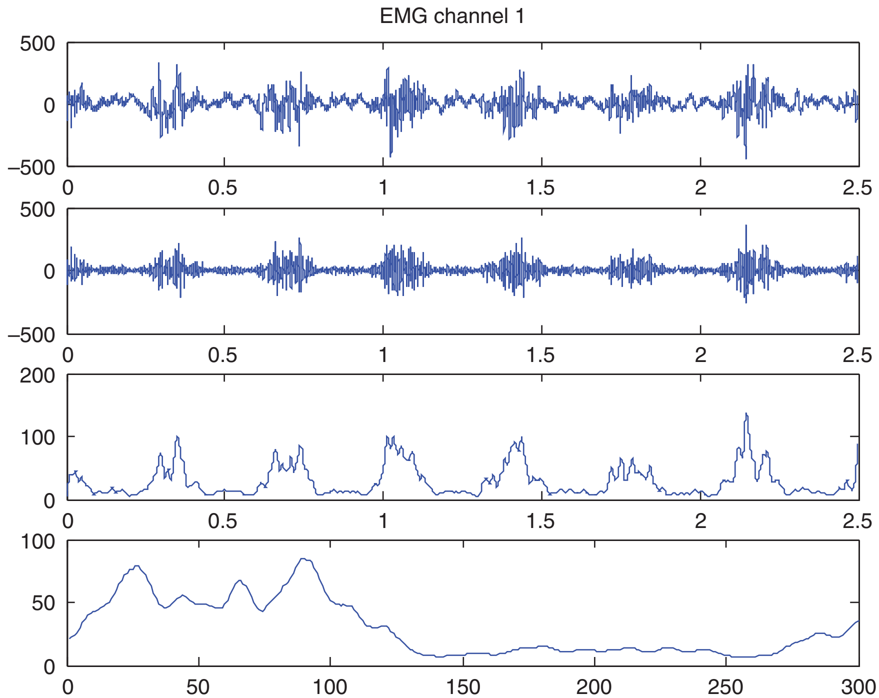


**Figure 2** A typical representation of raw and smooth rectified surface EMG of baseline walking for gluteus medius muscle. Each block represents in ascending order: (1) raw EMG recording, (2) high and low pass filtered, (3) full wave rectified and smoothed, (4) one selected gait cycle of data.

**Table 1** EMG values and temporo-spatial gait parameters

| | Baseline | Walking with cane | Walking with tape | Walking with TheraTogs |
|---|---|---|---|---|
| Mean % change of EMG for gluteus medius between baseline and intervention. (SD) | – | −21.8 (19.3) | 5.8 (28.2) | 16.4 (23.6) |
| Mean EMG mV (SD) gluteus medius | 76 (37) | 56 (31) | 78 (39) | 87 (47) |
| Median EMG mV gluteus medius | 82 | 61 | 87 | 107 |
| Mean % change of EMG for tensor fascia lata between baseline and intervention (SD) | – | −19.1 (29) | −3 (32) | −1.1 (28) |
| Mean EMG mV (SD) tensor fascia lata | 99 (77) | 74 (61) | 87 (60) | 91 (62) |
| Median EMG mV tensor fascia lata | 83 | 59 | 91 | 96 |
| Mean gait speed m/s (SD) | 0.44 (0.23) | 0.45 (0.17) | 0.48 (0.20) | 0.49 (0.17) |
| Mean step length asymmetry ratio (spatial asymmetry)[a] | 1.27 (0.87) | 0.91 (0.29) | 1.08 (0.30) | 0.93 (0.26) |
| Mean single limb support time ratio (temporal asymmetry)[b] | 1.24 (0.41) | 1.15 (0.25) | 1.30 (0.55) | 1.33 (0.47) |

[a]Values >1 represent longer step length with non-hemiplegic leg and vice versa.
[b]Values >1 represent longer single support time on non-hemiplegic leg

The effect size of TheraTogs use was −0.5 (large effect size by Cohen's benchmark).

Tape increased EMG activity from baseline by 5.8%. This change between cane use and tape was also statistically significant ($P = 0.001$) and the effect size −0.46 was medium to large.

No statistically significant difference was identified between TheraTogs and tape use ($P = 0.029$), although a small to medium effect size was calculated −0.30 in favour of TheraTogs use.

For tensor fascia lata, cane use reduced EMG activity from baseline by 19.14%. In this instance TheraTogs also reduced EMG activity from baseline by 1.10%. This represented a statistically significant difference between percentage change in peak EMG between cane use and TheraTogs ($P=0.009$). The effect size −0.37 was medium. EMG activity during tape walking was reduced by 3%. This difference between cane use and tape was not statistically significant. No significant difference between TheraTogs and tape was identified for tensor fascia lata.

Gait speed improved with TheraTogs and tape compared to baseline and cane walking although no statistically significant differences were found.

Step length asymmetry was greatest at baseline and was reduced during cane use and interventions. Symmetry was greatest with TheraTogs followed by tape then cane. Cane use and TheraTogs led to longer step lengths with the hemiplegic leg than the non-hemiplegic leg. Taping resulted in non-hemiplegic step lengths remaining longer than hemiplegic, as was the case at baseline, although the difference was reduced.

Temporal asymmetry was reduced from baseline only during cane use and was increased with both taping and TheraTogs. At baseline single support on the non-hemiplegic leg was longer than on the hemiplegic leg. This tendency was increased with TheraTogs and taping. Cane use led to increased single support on the hemiplegic leg.

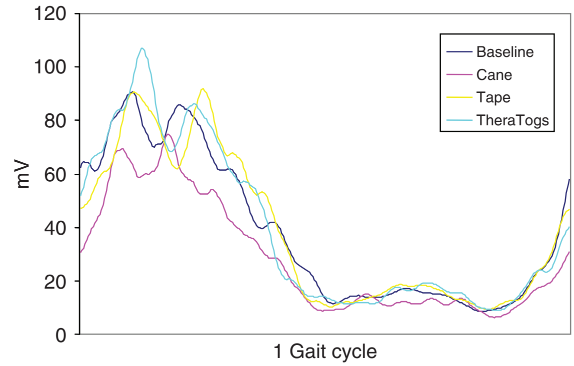


**Figure 3** Smooth rectified mean EMG graphs of gluteus medius muscle of a representative subject walking for one gait cycle (initial foot contact to subsequent foot contact) at baseline and during interventions.

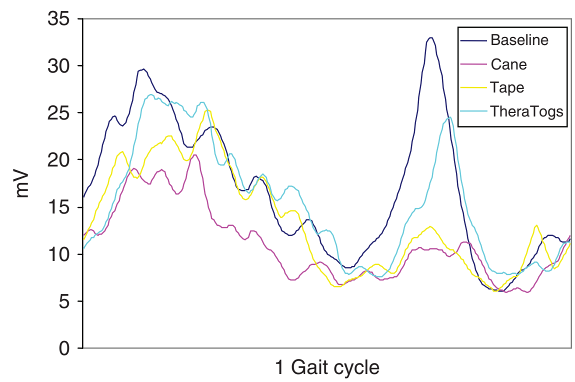


**Figure 4** Smooth rectified mean EMG graphs of the tensor fascia lata muscle of a representative subject walking for one gait cycle (initial foot contact to subsequent foot contact) at baseline and during interventions.

## Graphical representation

Processed EMG data was averaged for six gait cycles. The resulting mean EMG values were calculated for one gait cycle for both muscles during all interventions. Figures 3 and 4 graphically represent these values for one representative patient.

In Figure 3 mean EMG for cane use lies below the mean EMG for baseline throughout the majority of the gait cycle. Mean EMG values for tape and TheraTogs are higher than mean EMG for baseline throughout the gait cycle and peak EMGs for tape and TheraTogs are both clearly increased from baseline.

In Figure 4 mean EMG for cane use lies clearly below the mean EMG for baseline throughout the gait cycle. Mean EMGs for tape and TheraTogs show a tendency to lie between these two values with TheraTogs EMG values generally higher than tape and increased beyond baseline at some points.

## Possible effect modifiers

Pearson correlations were calculated for each muscle to see whether results were influenced by body mass index (BMI), time since stroke or variations in hip abductor muscle strength ratio. No statistically significant correlations were calculated.

## Discussion

The results of this investigation confirm the findings of other studies in both stroke and non-stroke subjects[1–4] that the EMG activity of hip abductor muscles is significantly reduced during cane walking, on the side contralateral to cane use. This study has shown, for the first time, that alternative treatment interventions are available which have the immediate effect of significantly increasing hip abductor muscle activity in stroke patients during walking as in the case of the gluteus medius, or have a significantly reduced negative effect as in the case of tensor fascia lata. Two of the three temporo-spatial gait parameters measured – gait speed and spatial asymmetry – were improved with TheraTogs and tape compared with baseline and cane walking. One parameter, temporal asymmetry, was worsened with TheraTogs and taping compared with baseline and cane walking.

Kirker *et al.*[12] have shown that hip abductor activity post stroke is primarily disrupted while initiating movement (e.g. taking a first step) and when responding to external perturbations. These abilities are important for independent walking at home and in the community. Interventions such as taping and TheraTogs which improve hip abductor activity during these movements may be more effective in promoting recovery than interventions which consistently reduce activity, as in cane use. These conclusions are supported by Kim and Eng[14] in a study to investigate the relationship between walking speed in stroke survivors and kinemetic and kinetic gait profiles. This study concluded that interventions which increase frontal plane hip powers by strengthening the hemiplegic hip abductors would increase gait speed.

Gait speed was increased with the interventions although no statistically significant differences were found between speeds and all gait speeds remained within the same functional category.[22,23] Schmid *et al.*[22] and Perry *et al.*[23] determined that household ambulation is equivalent to severe gait impairments and a walking speed of $<0.4$ m/s. Moderate gait impairments are equivalent to between 0.4 and 0.8 m/s and represent limited community ambulation. Full community ambulation indicates mild impairment and a walking speed of $>0.8$ m/s. In this study gait speed always remained within the middle category of moderate gait impairments (0.4–0.8 m/s). Although gait speed improved, neither treatment interventions nor cane use had the immediate effect of moving gait speed to a different functional category.

Step length asymmetry ratios showed that spatial symmetry was improved compared to baseline with both interventions and during cane use. However temporal asymmetry ratios were improved only during cane use and were increased, showing more asymmetry compared to baseline, with both interventions. As the temporo-spatial gait parameters of walking speed and symmetry have been shown to correlate with balance and lower limb function following stroke[21,22,24,25] the immediate improvement of two from three of these parameters may indicate that balance reactions are also stimulated during walking with taping and TheraTogs.

The use of surface EMG electrodes to assess several interventions, two of which cover the electrodes, could have been problematic. The quality of the EMG signal could have been compromised. Through visual assessment of the raw EMG signal between interventions, and by measurement of skin impedance at the beginning and end of each trial, signal quality was assured

One further drawback of the present study is the lack of information gained about the longer term effects of the interventions. Although the aim of the study was to assess the immediate effects of the interventions, clinical relevance cannot be assumed until these effects have been investigated over a longer time period.

The results of this study indicate that cane use may not be optimal during the early stages of gait rehabilitation following stroke. TheraTogs and taping may be more effective in promoting muscle activity and balance reactions. Clinical trials to assess and compare the long-term effects of the interventions and cane use are needed.

**Clinical messages**

- Cane walking following stroke reduces hemiplegic hip abductor muscle activity compared with walking without walking aids.
- Hip abductor taping and TheraTogs increase hemiplegic hip abductor activity and gait speed during walking compared with walking without aids or walking with a cane.

**Acknowledgements**

We would like to thank Georg Ferber for his statistical advice and assistance.

We would also like to thank Alfio Albasini for his advice relating to taping techniques.

**Source of equipment**

TheraTogs, Inc., Corporate Offices, 305 Society drive, Suite C-3, Telluride, Colorado 81435-8914, USA. TheraTogs orthoses were provided free of charge for research purposes from the above named company. No other financial support was or provided by this or any other company.

**Financial disclosure**

We certify that no party having a direct interest in the results of the research supporting this article has or will confer a benefit on us or on any organization with which we are associated

**Contributors**

CM: Initiated, jointly designed, jointly decided on analytic strategy, jointly analysed and wrote the article; is guarantor and ultimately responsible for the accuracy, honesty and morality of the study. JS: Participated in designing, deciding on analytic strategy and writing the article. MF: Assisted in initiating study and monitoring progress. JR: Participated in deciding on analytic strategy, assisted with analysis and writing.

## References

1 Buurke JH, Hermens HJ, Erren-Wolters CV, Nene AV. The effect of walking aids on muscle activation patterns during walking in stroke patients. *Gait Posture* 2005; **22**: 164–70.

2 Ajemian S, Thon D, Clare P, Kaul L, Zernicke RF, Loitz-Ramage B. Cane assisted gait biomechanics and electromyography after total hip arthroplasty. *Arch Phys Med Rehabil* 2004; **85**: 1966–71.

3 Neumann DA. Hip abductor muscle activity as subjects with hip prostheses walk with different methods of using a cane. *Phys Ther* 1998; **78**: 490–501.

4 Neumann DA. An electromyographic study of the hip abductor muscles as subjects with a hip prosthesis walked with different methods of using a cane and carrying a load. *Phys Ther* 1999; **79**: 1163–73.

5 Laufer Y. Effects of one point and four point canes on balance and weight distribution in patients with hemiparesis. *Clin Rehabil* 2002; **16**: 141–48.

6 Laufer Y. The effect of walking aids on balance and weight bearing patterns of patients with hemiparesis in various stance positions. *Phys Ther* 2003; **83**: 112–22.

7 Kuan TS, Tsou JY, Su FC. Hemiplegic gait of stroke patients: the effect of using a cane. *Arch Phys Med Rehabil* 1999; **80**: 777–84.

8 Mastos M, Miller K, Eliasson AC, Imms C. Goal directed training: linking theories of treatment to clinical practice for improved functional activities in daily life. *Clin Rehabil* 2007; **21**: 47–55.

9 Krakauer JW. Motor learning: its relevance to stroke recovery and neurorehabilitation. *Curr Opin Neurol* 2006; **19**: 84–90.

10 Huang VS, Krakauer JW. Robotic neurorehabilitation: a computational motor learning perspective. *J Neuroeng* 2009; **6**: 5.

11 Michael KM, Allen JK, Macko RF. Reduced ambulatory level after stroke: the role of balance, gait and cardiovascular fitness. *Arch Phys Med Rehabil* 2005; **86**: 1552–56.

12 Kirker SG, Simpson DS, Jenner JR, Wing AM. Stepping before standing:hip muscle function in stepping and standing balance after stroke. *J Neurol Neurosurg Psychiatry* 2000; **68**: 458–64.

13 Kirker SG, Jenner JR, Simpson DS, Wing AM. Changing patterns of postural hip muscle activity during recovery from stroke. *Clin Rehabil* 2000; **14**: 618–26.

14 Kim CM, Eng JJ. Magnitude and pattern of 3D kinematic and kinetic gait profiles in persons with stroke: relationship to walking speed. *Gait Posture* 2004; **20**: 140–46.

15 Holden MK, Gill KM, Magliozzi MR, Nathan J, Piehl-Baker L. Clinical gait assessment in the neurologically impaired: Reliability and meaningfulness. *Phys Ther* 1984; **64**: 35–40.

16 Folstein MF, Folstein SE, McHugh PR. 'Mini-mental state.' A practical method for grading the cognitive state of patients for the clinician. *J Psychiatr Res* 1975; **12**: 189–98.
17 Click Fenter P, Bellew JW, Pitts TA, Kay RE. Reliability of stabilised commercial dynamometers for measuring hip abductor muscle strength: a pilot study. *Br J Sports Med* 2003; **37**: 331–34.
18 Hermens HJ, Freriks B, Merletti R *et al*. *European recommendations for surface electromyography (SENIAM). CD-rom*. Enschede, Roessinghh Research and Development, 1999.
19 Konrad Peter. The ABC of EMG – *a practical introduction to kinesiological electromyography*. Scottsdale, AZ, Noraxon USA Inc.
20 Nadeau S, Arsenault AB, Gravel D, Bourbonnais D. Analysis of the clinical factors determining natural and maximal gait speeds in adults with a stroke. *Am J.Phys Med Rehabil* 1999; **78**: 123–30.
21 Brandstater ME, de Bruin H, Gowland C, Clark BM. Hemiplegic gait: analysis of temporal variables. *Arch Phys Med Rehabil* 1983; **64**: 583–87.
22 Schmid A, Duncan PW, Studenski S *et al*. Improvements in speed-based gait classifications are meaningful. *Stroke* 2007; **38**: 2096–100.
23 Perry J, Garrett M, Gronley JK, Mulroy SJ. Classification of walking handicap in the stroke population. *Stroke* 1995; **26**: 982–9.
24 Patterson KK, Parafianowicz I, Dannells CJ *et al*. Gait asymmetry in community – ambulating stroke survivors. *Arch Phys Med Rehabil* 2008; **89**: 304–10.
25 Witte US, Carlsson JY. Self selected walking speed in patients with hemiparesis after stroke. *Scand J. Rehabil Med* 1997; **29**: 161–65.