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The effect of walking aids on muscle activation patterns during walking in stroke patients

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Abstract

The purpose of this study was to investigate changes in muscle activation patterns with respect to timing and amplitude that occur when subjects with stroke walk with and without a walking aid. This knowledge could help therapists in deciding whether or not patients should use a cane or quad stick while walking.

Thirteen patients suffering from a first unilateral ischemic stroke participated in the study. Surface electromyography (SEMG) of the erector spinae, gluteus maximus, gluteus medius, vastus lateralis, semitendinosus, gastrocnemius and tibialis anterior of the affected side were measured during three different conditions: (1) walking without a walking aid, (2) walking with a cane and (3) walking with a quad stick. Timing and amplitude parameters of the activation patterns were quantified using an objective burst detection algorithm and statistically evaluated.

Results showed a statistically significant and clinically relevant decrease in burst duration of both erector spinae and tibialis anterior when walking with a cane. The amplitude of the vastus lateralis and tibialis anterior dropped when patients walked with a cane and quad stick.

The use of a cane should be considered when therapy is given to stroke patients to achieve normal muscle activation patterns.

Keywords: Stroke; Walking aids; Gait analysis; SEMG; Muscle coordination

1. Introduction

Regaining the ability to walk is a major goal during the rehabilitation of stroke patients [1]. Factors important to reach this goal are early, functional, goal oriented intensive training [2]. In clinical practice direct assistance during exercise is intentionally restricted and strong personal involvement of the patient is encouraged. Walking aids are often used to maintain safety and increase independence during gait training [3].

Different opinions exist on the effect of walking aids on the gait pattern of stroke patients. Kuan et al. [3] stated that the use of walking aids increases stability, reduces the chance of falling and improves independent walking. Lennon et al. [4], on the other hand, mentions that the use of walking aids might hinder the training of a symmetrical walking pattern, and Davies [5] considered that a walking aid should only be given to a stroke patient when he or she is able to walk without one. Very little evidence exists to support these assumptions. Only six studies investigated the effects of a walking aid on gait [3,6–10]. Results suggest that the use of a cane had positive effects on stride length and walking speed [3]. Other studies [8,10] did not measure significant change in walking speed when using a walking aid. Furthermore, neither significant effects on the symmetry of the walking pattern [9,10] nor on the symmetrical distribution of weight over the legs were demonstrated. The study of Tyson [9] presumes that walking aids had more effect on the lateral sway of the trunk rather than fore-aft sway.

No clear consensus exists of effects of walking aids on symmetry of gait, walking speed and weight bearing. Furthermore, there is a distinct paucity of detailed studies

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on muscle activation patterns. The Neuro Developmental Treatment (NDT) concept [5] is one of the most widely used approaches in stroke rehabilitation within Europe [10] and aims to improve recovery of the hemiplegic side by focussing on normalizing muscle function and symmetry [5]. However, in only one study were muscle activation patterns recorded [10]. Results showed that walking with a cane did not differ from walking without an aid with regards to the timing of muscle activation patterns and mean amplitude of activity. Muscle activation patterns were qualitatively rated and mean amplitude was only computed and statistically tested in selected intervals. Based on the study of Hof and van den Berg [11], who described that the amplitude of the electromyography (EMG) of muscles depends on the muscle force produced, one would expect to record lower amplitudes in EMG of anti gravity muscles when walking with a walking aid.

The objective of this study was to investigate changes in muscle activation timing and amplitude that occur when walking with and without a walking aid, using an objective automatic burst on and off detector [12].

2. Methods

2.1. Subjects

Stroke patients recruited from the Rehabilitation Centre ‘Het Roessingh’ in Enschede, The Netherlands were included in the study if they were aged between 40 and 75 years, had a first unilateral ischemic stroke and were able to walk without physical assistance (Functional Ambulation Categories (FAC) ≥ 3 [13]). They were required to walk approximately100 m with and without a walking aid for the measurements. Furthermore, sufficient cognitive abilities (Mini-mental State Examination (MMSE) ≥ 22) [14]) were required to participate. Patients were excluded if they have had more than one stroke or had other physical conditions adversely influencing walking ability. The medical ethics committee of the Rehabilitation Centre approved the study. All subjects signed an informed consent before participating in the experiment.

2.2. Experimental set-up and procedures

Selected patients were tested in three different conditions in randomized order: (1) walking without a walking aid, (2) walking with a cane and (3) walking with a quad stick.

All patients wore their own preferred shoes. Five patients used an ankle foot orthosis (AFO), three wore a plastic AFO in their shoes and two wore a double bar brace attached to the shoe. The canes used were normal height walking sticks with a normal grip. Normal height was defined as ‘at the level of the radial styloid of the sound wrist’ with the arm straight hanging down [15].

2.3. Muscle activation patterns

Activation patterns of erector spinae, gluteus maximus, gluteus medius, vastus lateralis, semitendinosus, gastrocnemius and tibialis anterior muscles on the affected side were assessed using surface electromyography. SEMG of these seven muscles was recorded during walking using an 8-channel K-lab KL-100 EMG amplifier. ‘Meditrace pellet #1801 graphics control’ electrodes were used. Electrode size (1 cm^2), inter electrode distance (2 cm), electrode placement and skin preparation were according to the ’SENIAM’ protocol [16]. The SEMG signals were band pass filtered (third order Butterworth high-pass filter −3 dB at 20 Hz, first order low-pass filter −3 dB at 500 Hz) and amplified. The SEMG signals were digitised at 1000 Hz sample rate with 12 bits resolution and stored by a VICON 370 system. The SEMG processing and parameter extraction was performed using MATLAB. At least 10 gait cycles were recorded for each subject with each condition and stored for further analysis.

Footswitches were used to determine stance and swing phase of both legs. The footswitches consisted of an aluminium conductive sheet covering the sole of the shoe in conjunction with a conductive rubber mat [17,18]. The SEMG and footswitch signals were collected within one session to make an accurate as possible within subject comparison. Walking speed was measured over a distance of 7.5 m using light gates to detect start and stop.

2.4. Data reduction

An objective method was implemented to automatically analyze the muscle activation patterns [12]. This method consisted of an automatic burst on and off detector of SEMG signal based on the approximated generalized likelihood ratio (AGLR) principle described by Staude and Wolf [19]. This algorithm was used to analyze the raw SEMG signals of every stride in the gait cycle separately with respect to the on- and off-times of muscle activation. Subsequently, all detected on- and off-times were normalized in time using the stride time starting from the related heel strike. SEMG was rectified and 25 Hz low-pass filtered and plotted together with the timing information along the x-axis (Fig. 1). Additionally the mean amplitude within the detected burst was calculated from this smoothed rectified EMG (SRE).

2.5. Statistical analysis

Data of the selected muscles were analyzed separately. Since the gathered data were not normally distributed the median on- and off-times in percentage of the gait cycle (together with the 25th and 75th percentiles) and the total burst duration (off-time minus on-time in percentage of gait cycle) were calculated for each subject. Differences in walking speed, median on- and off-times, burst duration and mean amplitude within the burst, between the interventions

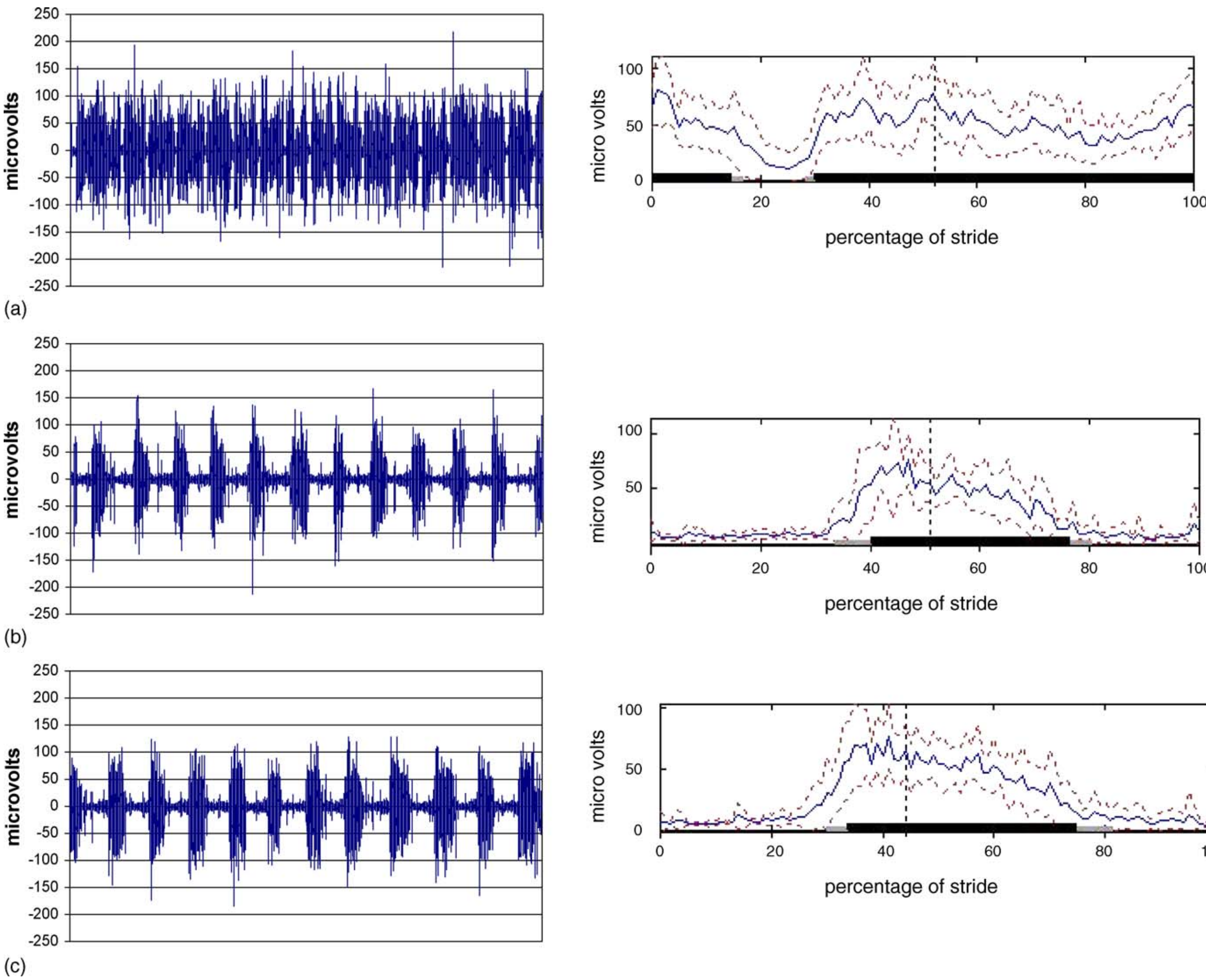

Fig. 1. Both raw EMG and stride normalized smooth rectified EMG (SRE) of the erector spinae is presented for the three different walking conditions. (a) The SEMG of the erector spinae when walking without an aid, (b) when walking with a cane and (c) when walking with a quad stick. Along the *y*-axis the amplitude of both raw SEMG and SRE in microvolts is presented. Along the *x*-axis of the stride normalized SRE graphs, the timing as derived from the burst detection algorithm is shown in black and gray lines. The median on- and off-time is presented in a black solid bar connecting the median on-time with the median off-time. The somewhat smaller little grey bars indicate the 25th and 75th percentiles of the median on- and off-times. The dashed vertical line represents toe off.

were analyzed statistically using the Friedman test in SPSS. The level of statistical significance was set at $p < 0.05$. Comparisons that showed significant differences were analysed post hoc using the Wilcoxon Signed Ranks test.

3. Results

3.1. Study population

Ten men and three women (mean age 63 years, range 50–72 years) participated in the study. They had a mean time since an ischaemic stroke of 205 days (range 47–385 days). All selected patients used a cane for walking during normal everyday activities. Ten patients had a left hemiplegia and three a right hemiplegia. The median FAC-score was 4 (range 3–5). All patients had sufficient cognitive abilities to participate in the study. Median MMSE was 28 (range 22–29).

3.2. Walking speed

Differences in walking speed during the three interventions are presented in Table 1.

Table 1
Descriptive statistics of walking speed during the three interventions

Walking speed	*N*	Mean (m/s)	S.D.	Percentiles		
				25th	50th (median)	75th
Without aid	13	.45	.19	.27	.42	.67
Cane	13	.44	.19	.23	.47	.61
Quad stick	13	.39	.14	.23	.40	.54

Statistical analysis of walking speed using the Friedman test showed no significant differences ($p = 0.193$). Post hoc testing using the Wilcoxon Signed Ranks test, however, revealed a statistical significantly lower walking speed ($p = 0.045$) when walking with a quad stick was compared to walking with a cane.

3.3. Muscle activation patterns

Fig. 1 shows a typical example of the muscle activation patterns of the erector spinae of one stroke patient when walking without a walking aid (Fig. 1a), with a cane (Fig. 1b) and when walking with a quad stick (Fig. 1c). Walking without an aid showed clear differences in timing compared to walking with a cane or a quad stick. When walking without an aid the erector spinae was almost continuously active throughout the gait cycle and a clear phasic activity was seen when walking with an aid. Differences between walking with a cane and walking with a quad stick were small and walking with a quad stick showed an earlier on-time compared to walking with a cane. The average amplitude did not differ much between the three different walking conditions.

3.4. Timing

Statistical analysis of the timing parameters measured during the three different walking conditions, using the Friedman test, showed significant differences for the burst duration of the erector spinae ($p = 0.006$), the on-time of the vastus lateralis ($p = 0.009$), the on-time of the tibialis anterior ($p = 0.008$) and the burst duration of the tibialis anterior ($p = 0.023$). Post hoc testing using the Wilcoxon Signed Ranks test (Table 2) showed a statistically significant decrease in burst duration of the erector spinae, when walking with a cane was compared to walking without an aid. Although not statistically significant, a similar tendency was observed when walking with a quad stick. The on-times of the vastus lateralis were significantly later during the stride when comparing walking with a quad stick and a cane and between walking with a quad stick and walking without an aid. The on-times of the tibialis anterior were significantly later during the stride when comparing walking with a quad stick and walking with a cane. Burst duration of the tibialis anterior decreased significantly while walking with a cane or with a quad stick compared to walking without an aid.

3.5. Amplitude

Statistical analysis, using the Friedman test, showed significant differences in the average amplitude of the burst of erector spinae ($p = 0.028$), gluteus maximus ($p = 0.004$), gluteus medius ($p = 0.004$), vastus lateralis ($p < 0.001$) and tibialis anterior ($p = 0.020$) measured during the three different walking conditions.

Post hoc testing using the Wilcoxon Signed Ranks test (Table 3) showed a statistically significant decrease in average amplitude of the erector spinae when comparing walking with a quad stick and walking without an aid, and between walking with a quad stick and walking with a cane. The decrease in the amplitude of gluteus maximus, gluteus medius and vastus lateralis was statistically significant when walking without an aid was compared to walking with a cane and walking with a quad stick. The decrease in amplitude of the tibialis anterior was statistically significant when walking with a quad stick was compared to walking without an aid and walking with a cane.

3.6. Clinical relevance

The 25th, 50th and 75th percentiles of the timing parameters were used to consider the clinical relevance of the described changes. Fig. 2 clearly shows the asymmetric distribution of the data. The 25th, 50th and 75th percentiles of the on-times of the vastus lateralis were close to normal [20,21]. The differences in on-times of the vastus lateralis

Table 2
Results of the post hoc testing of the difference in timing parameters, using the Wilcoxon Signed Ranks test

Timing	Compare	Negative ranks	Positive ranks	Ties	Total	Z	Asymp. sig. (2-tailed)
Erector spinae (burst duration)	Cane–without aid	11	2	0	13	−2.062	.039*
	Quad stick–without aid	11	2	0	13	−1.852	.064
	Quad stick–cane	4	9	0	13	−1.503	.133
Vastus lateralis (on-time)	Cane–without aid	7	6	0	13	−.175	.861
	Quad stick–without aid	2	11	0	13	−.1.992	.046*
	Quad stick–cane	2	11	0	13	−2.551	.011*
Tibialis anterior (on-time)	Cane–without aid	5	8	0	13	−.314	.753
	Quad stick–without aid	2	11	0	13	−1.712	.087
	Quad stick–cane	2	11	0	13	−2.691	.007*
Tibialis anterior (burst duration)	Cane–without aid	11	2	0	13	−2.411	.016*
	Quad stick–without aid	10	3	0	13	−2.062	.039*
	Quad stick–cane	8	5	0	13	−7.34	.463

* Significant difference.

Table 3
Results of the post hoc testing of the difference in amplitude using the Wilcoxon Signed Ranks test

Amplitude	Compare	Negative ranks	Positive ranks	Ties	Total	Z	Asymp. sig. (2-tailed)
Erector spinae	Cane–without aid	8	4	0	12	−1.412	.158
	Quad stick–without aid	10	2	0	12	−2.432	.015*
	Quad stick–cane	10	3	0	13	−2.201	.028*
Gluteus maximus	Cane–without aid	10	2	0	12	−2.040	.041*
	Quad stick–without aid	11	1	0	12	−2.275	.023*
	Quad stick–cane	9	4	0	13	−1.433	.152
Gluteus medius	Cane–without aid	10	2	0	12	−2.275	.023*
	Quad stick–without aid	11	1	0	12	−2.981	.003*
	Quad stick - cane	8	5	0	13	−1.153	.249
Vastus lateralis	Cane–without aid	11	1	0	12	−2.981	.003*
	Quad stick–without aid	12	0	0	12	−3.059	.002*
	Quad stick–cane	9	4	0	13	−1.363	.173
Tibialis anterior	Cane–without aid	8	4	0	12	−1.726	.084
	Quad stick–without aid	10	1	0	11	−2.756	.006*
	Quad stick–cane	9	3	0	12	−2.275	.023*

* Significant difference.

between the three walking conditions were only about 2.5% of the total stride time.

The on-times of the tibialis anterior show a major increase in the 25th, 50th and 75th percentiles when walking with a quad stick. Compared to normal this on-time was increasingly delayed and thus abnormal. Walking without an aid and walking with a cane showed on-times close to normal.

The 25th, 50th and 75th percentiles of the burst duration of the erector spinae and tibialis anterior drops and shifted towards more normal values when walking with a cane or quad stick.

The 25th, 50th and 75th percentiles of the amplitudes (Fig. 3) of the different muscles during three different walking conditions showed only small differences in the erector spinae, gluteus maximus and gluteus medius muscles. Larger changes were found in vastus lateralis and tibialis anterior.

4. Discussion

In the past the timing of muscular action was usually assessed by visual inspection of the raw EMG patterns or by studying the smooth rectified EMG profiles. In this study we used an objective motor onset detector based on the approximated generalized likelihood ratio principle developed by Staude and Wolf [19] and applied for burst detection in SEMG by Roetenberg et al. [12]. A considerable advantage of using such a burst detection algorithm is that it enables SEMG signals to be analysed objectively and automatically.

In contrast to the findings of Hesse et al. [10], we found significant changes in the muscle activation patterns and average amplitudes within the burst. Hesse et al. did not find any difference in walking with an aid when compared to walking without an aid. This difference in outcome might be because Hesse et al. calculated the differences in amplitude during pre-selected intervals, whereas in our study the total burst was taken into account. Differences in timing might be due to the method used. The automated burst detector might be more sensitive to change compared to visual observation of the SEMG signal.

Most important changes in timing were found in the burst duration of the tibialis anterior and erector spinae. Part of the decrease in burst duration of the tibialis anterior might have been due to the delayed on-time when walking with a quad

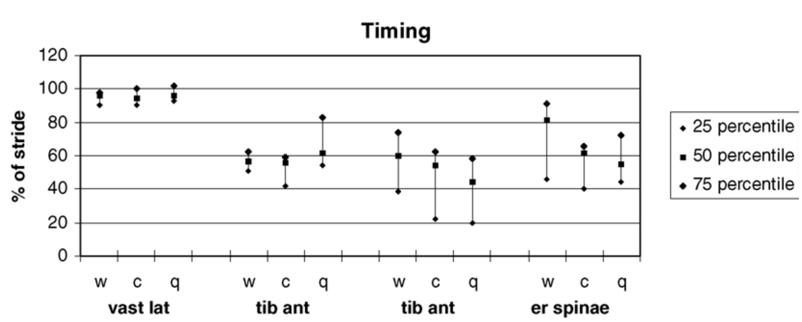

Fig. 2. The 25th, 50th and 75th percentiles of the difference in timing parameters. w: without aid; c: cane; q: quad stick. er spinae: erector spinae; glut med: gluteus medius; glut max: gluteus maximus; vast lat: vastus lateralis; tib ant: tibialis anterior.

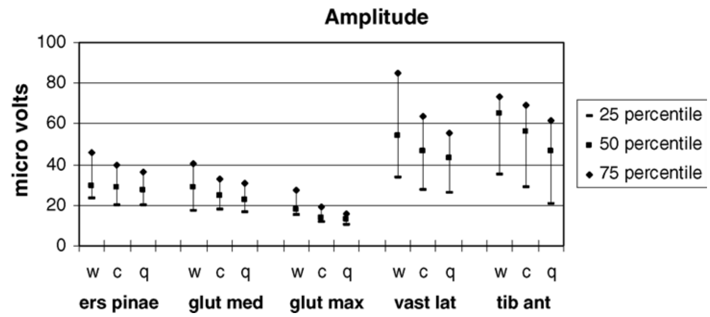

Fig. 3. The 25th, 50th and 75th percentiles of the difference in amplitude within the burst. w: without aid; c: cane; q: quad stick. er spinae: erector spinae; glut med: gluteus medius; glut max: gluteus maximus; vast lat: vastus lateralis; tib ant: tibialis anterior.

stick. The reason for this might be related to an increased lateral sway when using a quad stick, enabling foot-clearance without using the tibialis anterior muscle. The decrease in burst duration of the erector spinae seems to be related to the support of a walking aid. The activity of the erector spinae decreased during the period that weight was taken on the walking aid.

The reduced amplitudes of the anti gravity muscles (erector spinae, gluteus maximus, gluteus medius, vastus lateralis) were statistically different in this experiment but were not reported by Hesse et al. [10]. The reduction is in agreement with Hof and van den Berg [11] who stated that the amplitude of the EMG of muscles depends on the muscle force produced. When walking with a cane less muscle force is needed, because weight is taken on the cane, and thus less EMG activity is generated.

The median amplitudes (Fig. 3) of the different muscles during the three different walking conditions show that the most important changes were found in vastus lateralis and tibialis anterior. Changes in gluteus maximus, gluteus medius and erector spinae are less clear. The significant difference in amplitude in the tibialis anterior was unexpected. Walking without a walking aid induces higher amplitudes compared to walking with a cane or quad stick. Similarly, Hwang et al. [22] suggested that rail support during treadmill walking in hemi paretic patients reduced EMG linear envelope variability of the tibialis anterior. In stroke patients higher amplitudes of the tibialis together with an elongated burst duration is likely to cause a varus of the foot during stance and/or swing.

Hesse et al. [10] showed that the use of an AFO decreased the amplitude of the SEMG of the tibialis anterior during walking. In our experiment five out of 13 patients used an AFO. Comparisons between the three patients walking with a plastic AFO to those walking without an AFO did not reveal significant differences. The two patients wearing a double bar brace did differ from the other patients. Both burst duration and amplitude of the tibialis anterior increased when walking with a walking aid. The abnormal activation pattern of the tibialis anterior was seen alongside an abnormal activation pattern of the erector spinae when walking without a walking aid. This observation might explain the rationale behind NDT therapists believing that trunk stability is an important prerequisite for normal arm and leg movement. Overexertion may provoke abnormal tone and stereotypical mass patterns of the affected side [23].

Changes in muscle activation patterns were only measured in the affected leg and comparisons were made to normal because Shiavi et al. [24] showed that both the affected and unaffected leg in stroke patients can demonstrate abnormal muscle activation patterns.

An influence of walking speed on SEMG amplitude in the experiments cannot be excluded. Statistical analysis of walking speed revealed a significant difference when comparing walking with a quad stick with a cane. Table 3 shows that differences in amplitude of the erector spinae and tibialis anterior were found when comparing walking with a quad stick to walking with a cane. No significant differences in amplitude of gluteus maximus, gluteus medius and vastus lateralis were found when comparing walking with a cane and walking with a quad stick. However, differences in amplitude were statistically significant when walking without an aid was compared to walking with a cane and walking with a quad stick (Table 3). These findings underline that the differences in amplitude of these muscles are related to the support of the aid.

Although the reported changes were statistically significant there is still the question whether these changes are beneficial and thus clinically relevant. Since most therapies such as NDT [5] focus on relearning normal movements, changes in timing are thought to be clinically relevant when they become more normal as defined according to Perry [20] and Shiavi et al. [21]. Fig. 2 shows that the burst duration of the erector spinae and tibialis anterior dropped and shifted towards more normal values when walking with a cane or quad stick. Therefore these statistically significant changes can be considered clinically relevant. The 25th, 50th and 75th percentiles of the on-times of the vastus lateralis were close to normal. Differences in the 25th, 50th and 75th percentiles of the on-time of the vastus lateralis between the three walking conditions were only about 2.5% of the total stride time. Changes in the on-times of the vastus lateralis were so small that they would not be considered clinically relevant [25]. Walking with a quad stick induced abnormal on-times of the tibialis anterior whereas walking without an aid and walking with a cane show on-times close to normal.

5. Conclusion

The use of a cane resulted in less muscular effort, particularly of the vastus lateralis and was associated with a normalisation of muscle activation timing of the erector spinae and tibialis anterior. The use of a cane should be considered in the rehabilitation of stroke patients when therapy aims at normalisation of muscle activation patterns.

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