

# GAIT ANALYSIS IN STROKE PATIENTS - COMPENSATORY STRATEGIES

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## REZUMAT

**Obiectiv:** Scopul acestei lucrări este de a analiza strategiile motorii utilizate de pacientul hemiplegic. **Material și metode:** Au fost luați în studiu 10 pacienți hemiplegici (2 femei și 8 bărbați). Toți au prezentat în antecedente accidente vasculare cerebrale ischemice de origine sylviană. Am utilizat sistemul ELITE pentru a înregistra și analiza parametrii spațio-temporali și cinetici ai mersului. **Rezultate și concluzii:** Toți pacienții luați în studiu au prezentat valori anormale ale parametrilor temporali și cinetici, ceea ce explică caracterul asimetric al mersului. Analiza statistică a momentelor de forță (utilizând programul software Spad) evidențiază strategiile adaptative motorii utilizate de pacientul hemiplegic pentru a efectua locomoția la o viteză convenabilă.

**Cuvinte cheie:** mers, hemiplegie, cinetică, strategii motorii

## ABSTRACT

**Objective:** The purpose of this study is to analyse the motor strategies involved in abnormal gait by hemiplegic patients. **Material and methods:** The gait patterns of 10 hemiplegic patients (2 females and 8 males) who had a single stroke due to obstruction of the middle cerebral artery were recorded. The optoelectronic ELITE system was used to record and analyse the gait pattern of the hemiplegic subjects. The investigated parameters are: spatial-temporal and kinetic parameters. **Results and conclusions:** We have found abnormal temporal and kinetic patterns at all the patients which explain the asymmetrical pattern of gait. Analysing the moments of force through the Spad software we noticed that hemiplegic patients used motor adaptative strategies in order to reach a reasonable speed and perform walking.

**Key Words:** gait, hemiplegia, kinetics, motor strategy

## INTRODUCTION

Walking is often the prime target of rehabilitation because of its importance to functional independence. The ability to walk and a symmetrical gait are the prime factors that determine whether a patient will return to the previous level of productivity after stroke.

The gait analysis over the stride period informs us about spatial-temporal variables (speed, cadence, stance time, swing time, step length), kinematical variables (joint angles and velocities, foot and trunk trajectories), kinetic variables (reaction forces, moments of force, mechanical power) and EMG profiles of different muscles.<sup>1</sup>

We have seen in our practice that hemiplegics patients learned an individual gait pattern adapting themselves to specific circumstances in using motors adaptive strategies.<sup>2-4</sup>

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## OBJECTIVES

In our study we demonstrate that kinetic variables (moments of force) offers data on gait strategies employed by hemiplegic patients.<sup>4</sup>

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## **MATERIALS AND METHODS**

Ten patients (2 females, 8 males) with gait disorders secondary to a cerebrovascular accident were observed in the Human Motion Laboratory of the Brugmann Hospital in Brussels.

The study concerned patients admitted in the rehabilitation unit after a stroke (average 65.6 years) and included only patients who had a stroke due to obstruction of the middle cerebral artery. Six patients had hemiplegia on the right side, and four, on the left side.

After preliminary information regarding the study was provided, an informed consent was obtained from each patient included in the experimental group.

During the stay in the rehabilitation unit, all patients received 2 hours of individual physical therapy based on the Bobath technique, daily for 5 days a week; when needed, patients also underwent 1 hour of occupational therapy, and 1 hour of speech therapy.

Patients included in the protocol fulfilled the following criteria: (1) computerized tomography (CT) or magnetic resonance imaging showing a single ischemic monohemispheric lesion; (2) first stroke due to middle cerebral artery infarct; (3) subjects had to be ambulatory and able to follow our instruction. They were excluded if CT scan demonstrated primary cerebral hemorrhage or a lacunar infarct or if they were unable to understand simple orders.

The patients were encouraged to walk on the laboratory floor (0.6 m wide and 8 m long) as naturally as possible, from one end to another of the ground band passing by the force-plate. The third step was placed on the surface of the force-plate. The step was acceptable if the whole foot and no part of the contralateral foot landed on the force plate during stride.

Temporal and kinetic variables were recorded and analyzed using the optoelectronic ELITE system.<sup>5,6</sup>

This system consists of 6 cameras detecting retro-reflective markers using a sampling rate of 100 Hz. The cameras were placed 1 m above the floor, 6 m apart.

After calibration, the two-dimensional data were corrected for optical distortion and converted to 3D coordinate according to Lacquaniti et al.<sup>6,7</sup> The position in space of ten passive markers, including nine links, was recorded. Spherical reflective markers (1.5 cm in diameter) were fastened on to the skin overlying the following bony landmarks: the meatus of the ear, the acromial process, the lateral condyle of the elbow, the styloid process of the wrist, the tubercle of the anterosuperior iliac crest, the greater trochanter, the lateral condyle of the knee, the lateral maleolus and

the fifth metatarsal.

Surface electrodes were placed 1 cm over four leg muscles (anterior tibial, rectus femoris, gastrocnemius and biceps femoral).

A Kristler force platform (0.6 x 0.4 m) monitored the ground reaction forces along the vertical, longitudinal, lateral directions and the moments of force.

Statistical analysis was performed using the Spad software (multivariable statistic) which allows a detailed study of a large number of variables.<sup>8</sup> We have used two methods: agglomerative hierarchical clustering (AHC) and principal components analysis (PCA).

The principal components analysis (PCA) is a method that can be used to simplify a dataset; more formally it is a transformation that chooses a new system of coordinates for the data set such that the greatest variance by any projection of the data set comes to lie on the first axis (then called the first principal component), the second greatest variance on the second axis, and so on.

PCA can be used for reducing a large number of variables and retains those characteristics of the dataset that contribute most to its variance by eliminating the later principal components.

Hierarchical clustering algorithm is a common technique for data analysis, which consists of partitioning data set into subsets (clusters), so that the data in each subset (ideally) shares some common trait - often similarity or proximity for some defined distance measurements. A cluster is therefore a collection of variables which are "similar" between them and are "dissimilar" to the variables belonging to other clusters. Through this method we decide to cluster our subjects in five homogeneous groups.

The investigated spatial-temporal parameters are: stance time, swing time, cadence, walking speed, step width. We have measured the moments of force about the ankle, knee and hip joints during the stance phase of walking. All data were normalized according to body mass (N.m/kg).

The investigated kinetic parameters are:

- Peak knee extension moment (MKMAX); peak knee flexion moment (MKMIN);
- Peak ankle dorsiflexion moment (MAMIN); peak ankle plantar flexion (MAMAX);
- Peak hip extension moment (MHMAX); peak hip flexion moment (MHMIN).

The polarity convention used for all moments was positive for internal extension moments of the hip and knee but also for the plantar flexion moment of the ankle.

## RESULTS

All the patients showed a decrease in walking speed. The reduction of walking speed was related to reduction in both the length of the stride and cadence.<sup>9</sup>

The six hemiplegic patients on the right side presented a prolonged swing phase and a reduced stance phase on the affected side. The other four patients presented a prolonged stance phase and a reduced swing phase on the left affected side.

All the patients showed a large step width. They demonstrate a limitation in the capacity to shift weight and to load the hemiplegic leg during walking.

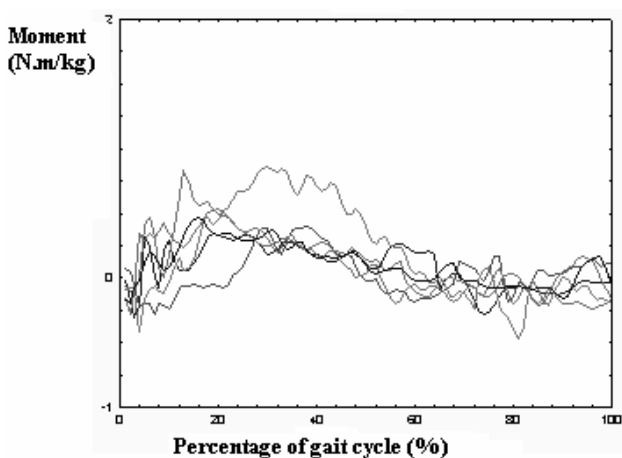
Using the norms described by Winter we compared moments of force about hip, knee and ankle joints. (Table 1)

**Table 1.** Mean and standard deviation of moment variables (in Newton-meters per kilogram) described by Winter.

Moments of force (Nm/kg)	Mean	SD
Knee flexion moment	-0.19	0.08
Knee extension moment	0.37	0.19
Hip extensor moment	0.36	0.13
Hip flexion moment	-0.55	0.25
Ankle dorsiflexion moment	-0.06	0.05
Ankle plantar flexion moment	1.07	0.28

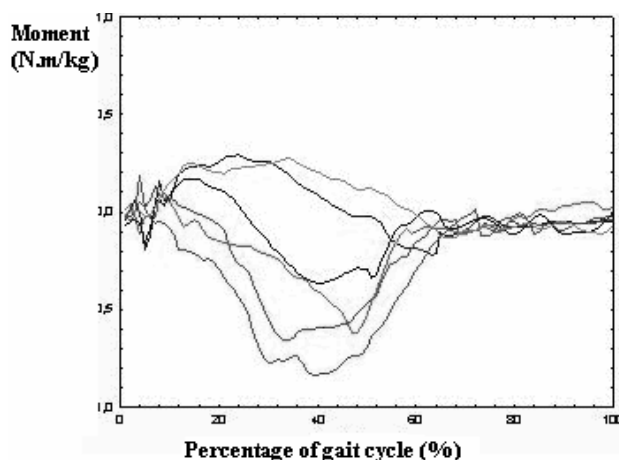
All our patients presented abnormal kinetics pattern in the hip, knee and ankle joints.

Six of our subjects showed extensor moment dominance about the hip joint after heel-strike and no flexor moment which normally occurs in the middle of the stance phase. (Fig. 1)



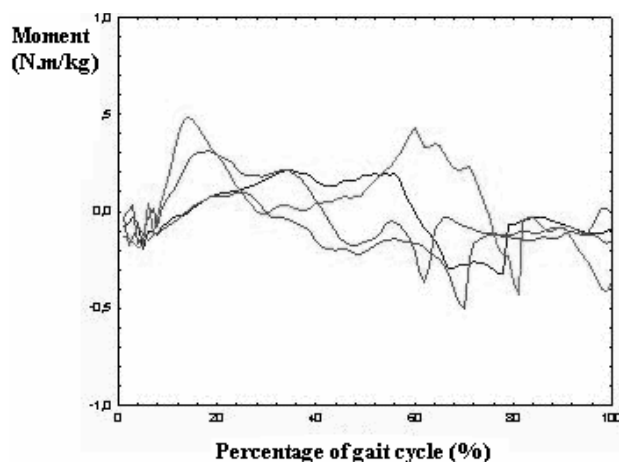
**Figure 1.** Moments of force about the hip joint. Six patients showed a very high extensor moment about the hip joint which is present in all the stance phase. We noticed the absence of the hip flexor moment in the middle of the stance (15-30% of gait cycle).

Three of our patients showed a pronounced flexor moment about the knee joint in the middle of the stance phase, while other three patients presented no flexor moment but a very high extensor moment about this joint. (Fig. 2)



**Figure 2.** Moments of force about the knee joint. Three patients showed pronounced flexor moments about the knee joint while other three patients presented no flexor moments but very high extensor moments about this joint.

The absence of the flexor moment about the knee joint with the presence of extensor dominance about this joint was also found at other four subjects. (Fig. 3)

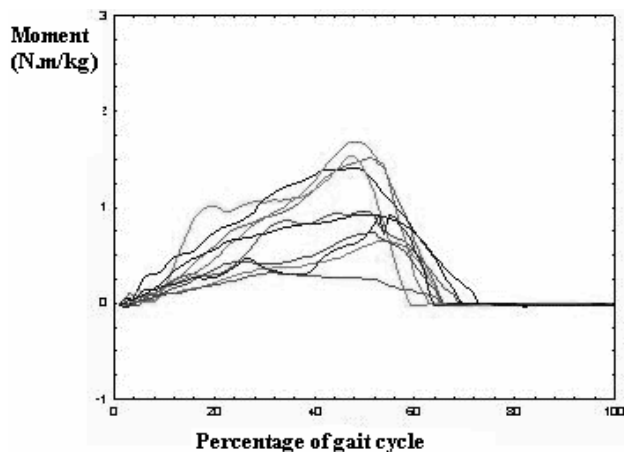


**Figure 3.** Moments of force about the knee joint. Patients with high extension moments about the knee joint in early stance which continue during all the stance phase.

An interesting observation was that all the subjects presented very high plantar flexion moments after the heel-strike which coincide with hyperactive plantar flexors and low anterior tibialis activity. (Fig. 4)

Statistical analysis brought out that certain variables are correlated with speed walking ( $0.01 < p < 0.05$ ). Thus, we observed a negative correlation between walking speed and the variable stance on the affected side (the proportion of the gait cycle occupied by the

stance phase is smaller and the speed is higher) ( $r = -0.63$ ).



**Figure 4.** Moments of force about the ankle joint. All patients presented very high plantar flexion moments and no dorsiflexion moments after the heel-strike.

The speed was also correlated with all the relative moments about the knee joint ( $r = 0.51$ ). This correlation was higher than the association between speed and the moments about hip and ankle joints. We analyzed only the affected side.

Statistical analysis using the Spad Software (AHC) allows us to cluster the subjects into five groups whose “members” had similar patterns. (Table 2)

Subjects from group 1 and 2 presented very high extension moments about the knee joint and high extension moments about the hip and ankle joints. The gait of those patients was asymmetrical but they can perform walking with a reasonable speed.

The patients from group 3 had no moments of sufficient magnitude and therefore their gait was abnormal. The subjects from group 4 and 5 presented low moments about the knee joint associated with high moments about the hip and ankle joints. Three of them associated flexor moments about the knee joint with high plantar flexion moments about the ankle joint. This compensation allows them to perform a good locomotion.

**Table 2.** Statistical analysis using the Spad Software.

Gr.	Composition	Speed	Stance phase	MKMIN	MKMAX	MHMIN	MHMAX	MAMIN	MAMAX
1	Patients 1, 5	0.6450	625.000	-0.2931	0.3021	-0.3912	0.5630	-0.0201	0.9583
2	Patient 9	0.6200	810.000	-0.4341	0.4881	-0.4905	1.1258	-0.0278	2.2578
3	Patients 3, 10	0.3500	745.000	-0.2281	0.2432	-0.2204	0.5378	-0.0149	0.7040
4	Other patients	0.4325	650.000	-0.5360	0.1236	-0.2190	0.6124	-0.0227	1.1712
5	Patient 6	0.2400	720.000	-0.8393	0.1858	-0.4692	0.8596	-0.0325	1.4093
Mean	-	0.4580	687.000	-0.4460	0.2259	-0.3059	0.6637	-0.0221	1.1676

## DISCUSSIONS

The results demonstrated abnormal spatial-temporal parameters in all hemiplegic patients.

Slow gait speed and step length were noticed in all patients. The cadence decreased in 6 patients and the step width was important in 5 subjects.

The right hemiplegic patients presented a prolonged swing phase and a reduced stance phase on the hemiparetic side. The prolonged duration of the swing phase on the hemiplegic side was associated with a decrease in speed.

Similar findings were observed by other authors.<sup>11-13</sup> They reported a negative correlation between walking speed and stance phase.

In the ten patients, abnormal kinetic patterns were present in the hip, knee and the ankle; they were most abnormal in the knee.

We have noticed that all patients had very high plantar flexor moment which coincides with hyperactive plantar flexors and low tibialis anterior activity.

Similar results were reported by Winter et al, which explained that the landing flat-foot of the hemiplegic patient coincides with a low anterior tibialis activity.<sup>14</sup>

The high hip extensor pattern evident in the hip moment is due to biceps femoral hyperactivity. The hyperactive hip extensors are a compensation to generate forward propulsion.<sup>14</sup>

We observed two abnormal patterns in the knee moment:

- A very high knee flexor in the middle of the stance phase caused by an eccentric activity in the gastrocnemius.
- A very high extensor moment in early stance which continues during all the stance phase caused by an eccentric activity in quadriceps.

According to Winter, the knee moment profile is strongly biased towards a flexor pattern that coincides with our results.<sup>14</sup>

The most striking finding in our study was that the subjects with high extensor moment about the knee joint present, in compensation, high extension

moment about the hip and ankle joints. We have also found that patients with low moments about the knee joint associated high moments about hip and ankle joints.

According to Simonsen et al, the combination of an extensor moment about the hip and a flexor moment about the knee joint can direct the ground reaction vector in forward direction. In contrast, extensor moments about both joints would turn the ground reaction vector in a backward direction, which opposes the direction of movement.<sup>15</sup>

In our study, only 3 subjects presented a combination of an extensor moment about the hip and flexor moment about the knee joint.

We suggest that an ankle plantar flexor moment does tend to produce a knee extensor moment, but in order to attain the temporal trajectory of joint angle positions it is necessary to produce a knee joint flexor moment, otherwise the subjects would walk stiff with extended knee joints.

Our findings confirmed the observation of Simonsen et al. that “individuals can perform the same task using very different dynamic strategies”.<sup>15</sup>

There are some limitations to the methodology used in this study. First, the model representing the body was a simple one and we didn't analyzed pelvic motion. The pelvic inclusion would have provided additional insight at this stage of our knowledge about the kinetics of hemiparetic gait.

Second, the analysis was limited to kinetic and spatial-temporal parameters. The examination of other variables as, kinematic variables, mechanical energy, work and power, could explain more closely all the mechanisms and on motor strategies employed by hemiplegic patients.

A third problem is involved in selecting the centers of reflective markers, magnitude of error in this and similar laboratories has been found to be about 1 mm RMS (root mean square). Despite using landmarks for marker placement, there is some variation in placement from subject to subject. All variations will produce some error in the results.

## **CONCLUSIONS**

Motor strategies, defined by kinetic, kinematic and/or muscle activation patterns, reflect neural planning of movement, which takes into account central as well as peripheral constraints.

The function of the knee joint flexor seen just after heel strike is to direct the resulting ground reaction

vector towards a desirable direction and minimize the loss of forward speed. To accomplish, a knee joint flexor moment and an extensor moment about the hip seem the only possible solution.<sup>15</sup>

Moments of force analyzed in our study offers data on motor strategies employed by hemiplegic patients. In order to reach a reasonable speed and to perform walking our patients used two strategies:

- Patients with a low flexor moment about the knee joint presented in compensation a large plantar flexor moment about the ankle joint (3 patients from group 4 and 5).

- Patients with an extensor moment about the knee joint associated an extensor moment about the hip joint (patients from group 1 and 2).

This method is probably the most accurate approach to the strategy that the hemiplegic patient has to promote for walking, according to his motor impairment.

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