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GAIT MEASUREMENTS AND MOTOR RECOVERY AFTER STROKE

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Gait analysis is one of the methods used for estimation of the degree of restoration of motor recovery after stroke. The purpose of the present study was to examine the diagnostic value of the footprint parameters and their relationship with the functional ambulation profile (FAP) scores provided automatically by the pressure sensor walkway system for gait examination. The patterns of walking were studied in a group of 23 patients with chronic unilateral stroke and 72 healthy subjects. Among the measured gait variables the peak times of the footprints were found as most informative parameters. Their predictive value was compared with some other gait indicators for motor recovery after stroke.

1. Introduction

Gait abnormalities after chronic unilateral stroke have been clinically evaluated and described by a number of investigators using different methods [1],[3],[6],[7]. Most of the techniques however are time consuming or otherwise insufficient for collecting reliable data. Recent technology has resulted in flexible and portable walkways with embedded pressure sensitive sensors. The pressure sensor system records the location of activated sensors and the time of their activation and deactivation. It provides the spatial and temporal variables of gait along with a dynamic pressure mapping of each footprint during walking [4],[5]. The clinical applicability of this technique is under investigation.

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The purpose of the present study was to examine the diagnostic value of the pressure sensor system GAITRite for distinguish gait abnormalities after stroke using the estimation of footprint parameters and functional ambulation profile (FAP) scores provided automatically by the equipment.

2. Gait Equipment and Recordings

All gait measurements were performed with a portable GAITRite system (MAP/ CIR Inc., Havertown, PA). This system consists of an electronic walkway of 4.57 m with an active area of 3.66 × 0.61 m, where the sensor pads are encapsulated. 13,824 sensors, each 1 cm in diameter, are arranged in a 48 × 288 grid pattern. Detail information about the methodology is given in [8]. The system continuously scans the sensors, provides information about the geometry of the footprints in 2-D space and gives a dynamic pressure mapping during walking by recording the location of activated sensors and the time of sensor activation/deactivation. At least one complete stride for each side inside the walkway is required to complete the computation. Measurements of the spatial and temporal gait variables are based on the geometric centers of heels for each of the 3 consecutive footprints (Figure 1). The subjects were asked to walk twice across the walkway without shoes. The average of both trials was analyzed. The walking distance (cm) and the ambulation time (s) were obtained from the heel centers of the first and last footprints.

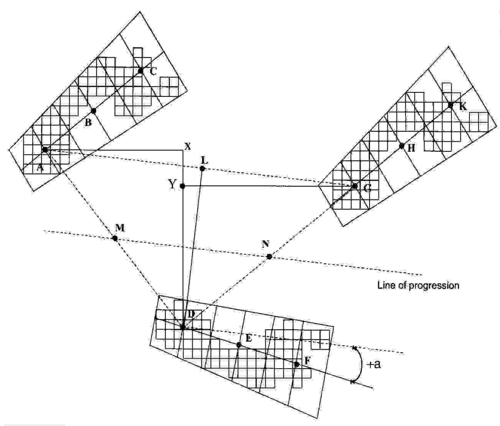

Figure 1: The series of three footprints.

Each footprint is divided into 12 trapezoids. Points A, D and G are the geometric centers of the heel for each footprint [2].

The Functional Ambulation Profile (FAP) scores are calculated by the system as a general indicator for the tested patient. The algorithm of FAP calculation includes following steps [2]:

1) For each limb the step length (measured electronically by the walkway) is divided by the leg length (measured manually) to produce the Step Length/Leg Length ratio (SL/LL), at the patient's preferred velocity. The velocity, collected over the 3.66 meters of the GAITRite active area is divided by the patient's mean leg length to produce the mean normalized velocity expressed in Leg Lengths per second (LL/sec).

2) For each limb, the SL/LL ratio, the step time and the mean normalized velocity are then compared on a model of regression lines to determine their deviations from the normal. This constitutes 44% of the total score, or 22% for each limb's performance.

3) The degree of asymmetry is calculated by subtracting the SL/LL ratios of each limb and then compared to normal, representing 8% of the total score.

4) The dynamic base of support, measured by the GAITRite walkway is also compared to normal, representing 8% of the total score.

5) Use of assisting devices such as orthoses, splints etc. represent 5% of the total score. Ambulatory aids such as canes, crutches, or walkers represent 5% of the total score.

The final score is derived subtracting points from a maximum score of 100. The maximum score of 100 is obtained at ordinary speed when step extremity ratios and step times are symmetrical and a dynamic base of support is less than 10 cm (see [5], [8]).

So defined FAP score is not sufficiently convincing and manual operations are necessarily. Our hypothesis is that among measured parameters exist more informative ones.

According the recording system, the footprint was divided into 12 trapezoids, 6 for the lateral part and 6 for the medial part. Each trapezoid, includes a specific number of sensors and the order for assigning sensor activation is heel-to-toe. The following parameters were evaluated for each trapezoid: segmental integrated pressure over time (P*t) (expressed as a percent of the overall integrated pressure over time), peak time (s) (first time point of each trapezoid when one or more sensors within a segment is at the maximum switching level), active area (expressed as a percent of the sum of the active sensors within one segment) and peak pressure (the maximum switching level expressed as a percent of the overall maximum switching level at the peak time in a segment). Detailed explanation of technology of the footprint measurements is given in [9].

All mentioned variables were tested as predictors in models for degree of motor recovery.

3. The Sample

For the purpose of the study 3 experimental groups were measured:

The first group (A) consisted from 23 patients (16 men and 7 women, mean age 54.8 ± 6.9 years, range 38-65 years; mean height 170.8 ± 8.8 cm, mean weight 82.8 ± 18.9 kg) with residual hemiparesis due to stroke. Some patients had survived unilateral cerebral infarction in the middle cerebral artery territory and others had a unilateral cerebral hemorrhage. They walked with a preferred ordinary speed.

The second group (B) included 62 clinically healthy subjects (21 men and 41 women, mean age 41.41 ± 11.0 years, range 21-61 years, mean height 1.70 ± 10.09 m, mean weight 71.61 ± 11.6 kg).They were non homogeneous set of people without explicit illness and walked with a preferred ordinary speed.

In the third group (C) were enrolled 10 clinically healthy subjects (5 men and 5 women, mean age 50.9 ± 4.4 years, range 46-58 years, mean height 1.69 ± 0.09 m, mean weight 77.6 ± 23.4kg). Fifty measurements were taken at 5 different speeds (from very slow to very fast). The velocity performance was divided into 5 categories: < 40 cm/s, 40-70 cm/s, 70-100 cm/s, 100-130 cm/s and > 160 cm/s. All patients and healthy subjects were engaged in a small training session and they gave an informed consent prior to the study.

4. Results and discussion

The description of the algorithm calculating the FAP score is not enough to be reproduced. Nevertheless it is clear that the value of the FAP score depends on the velocity of the tested person. The scatter plot of Velocity and FAP score of patients of group (A) and volunteers in group (C) illustrate our suspicions (Figure 2.

The FAP score falls when velocity is small as well higher than 160 cm/s. Decreasing the velocity is not sufficient to distinguish the ailing from healthy persons.

Most of the reported gait measurements are unidimensional (velocity, cadence, FAP scores etc.) or bidimensional (left and right stance time, swing time, step length, etc.) averaged characteristics. The latter are commonly used to indicate some gait asymmetry.

As shown earlier, there were four indicators, reported by the system for every one of the twelve trapezoids of each footprint. We chose one of them, namely

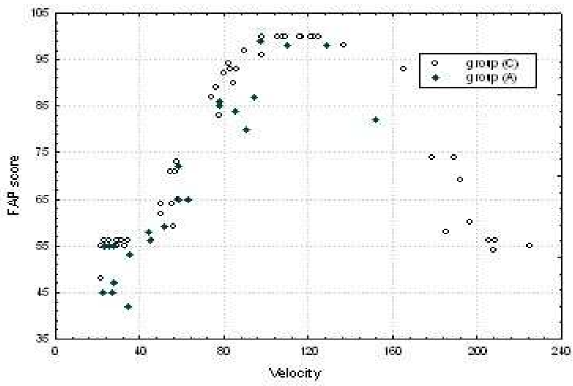

Figure 2: Scatter plot of Velocity versus FAP score points. The dependence follows a nonlinear function . The FAP scores fall when velocity were smaller than 80 cm/s and higher than 160 cm/s.

"Peak-time", as more informative for some deviations of the manner of the steps. Our choice was based on numerical experiments with correlation matrix of those four sets of parameters evaluated on the three experimental groups and their combinations. As an example, for the peak time using the homogenous group (C) we found that the first principal component explains 85% of total variance. Another control group (B) is more variable and only 45% are explained from first two principal components. The combination of the groups (A) and (C) gives 81% explained variation for two factors (principal components). The scatter plot (Figure 3) of that two groups ((A) and (C)) over the two factors suggests that the two groups may be distinguished using peak-time characteristics.

Adding group (A) to group (C) increased the number of factors in the analysis from one (when only (C) was included in analysis) to two. There were not such effect combining the groups (A) and (B).

Our hypothesis was confirmed in the next phase of the investigations, namely the linear discriminant analysis. First we applied the procedure to the groups (A) and (C) as training sample. As a result (see table 1) we had 98% correct classification of the group (C) and 82.6% correct classification in the group (A). The total correct classification was 93.15%. Posterior probabilities of the control group (B) gave 59 right classifications of 62 examined persons or 95.16 %.

A similar attempt was performed using groups (A) and (B) as training sample. The classification of the both groups was a little bit better, but posterior probabilities on control group (C) now is extremely indicative(see table 2).

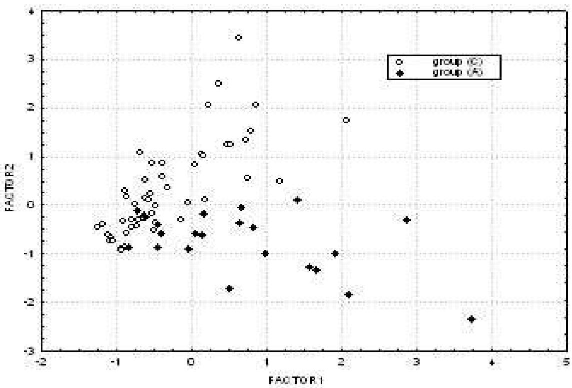

Figure 3: The principal component analysis of the footprint peak times in patients and controls. The projection of the all footprint peak time observations of the two common factors differentiated stroke gait from normal walking.

Group	Classified as	good walkers	bad walkers	Correct classifications
(A)	(23 bad)	4	19	82.61%
(C)	(50 good)	49	1	98.00%
	Total			93.15%
(B)	(62 good)	59	3	95.16%

Table 1: The classification table: the groups (A) and (C) as training sample.

5. Conclusions

Our study reveals that a pressure sensor system GAITRite is a reliable screening instrument for detection of gait abnormalities after chronic unilateral stroke based on the footprint peak time measurements. By testing the volunteers at different walking velocities as a training sample more reliable information for gait quality is possible to obtain.

There are optimistic conjectures that a better diagnostics are to be attained. First, using more flexible nonlinear algorhytm [10] for estimation of discrimination rule. Second, detailed information from the equipment including dynamics of the gait and higher order statistics.

Group	Classified as	good walkers	bad walkers	Correct classifications
(A)	(23 bad)	3	20	86.96%
(B)	(62 good)	62	0	100.00%
	Total			96.47%
(C)	(5×10 good)	31	19	62.00%
velocity	categories:			
	< 40 cm/s	0	10	0.00%
	40-70 cm/s	5	5	50.00%
	70-100 cm/s	7	3	70.00%
	100-130 cm/s	9	1	90.00%
	> 160 cm/s	10	0	100.00%

Table 2: The classification table: groups (A) and (B) as training sample

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