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Variability of gait characterized by normalized deviation

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The purpose of this study was to investigate the influence of sport, age and different orthopeadical diseases on the variability of gait. 45 healthy, young subjects, 11 professional hand ball players, 24 patients after medial meniscectomy, 20 elderly, healthy subjects, and 20 patients with hip osteoarthritis were examined. The average, the standard deviation and the normalized deviation of spatial and temporal parameters were calculated for each person examined and in each group. Our data suggested that the normalized deviation of parameters enables the modelling of dynamic perception, because it is independent of parameter values due to normalization. Our tests show that the size of the parameter is independent of lateral dominance in healthy subjects. The magnitude of the coefficient of the variation of parameters depends on age, on the intensity of sports activities, and on orthopaedical diseases.

Key words: *gait analysis, dynamic perception, normalized deviation*

1. Introduction

The evaluation of gait parameters during walking is helpful in assessing abnormal gait, in quantifying improvements resulting from intervention, or in predicting subsequent events such as ageing or falls. One of the most interesting parts of gait analysis is the study of gait variability. Gait variability can be characterized by the standard deviation of spatial, temporal, and angular parameters [1]–[5], and/or by their normalized deviation [6]–[9]. Normalized deviation can be defined as the proportion of standard deviation to average. Previous studies demonstrated that gait variability was significantly higher in elderly people than in youngsters [4]–[9]; however, the reason for this difference is not fully explained yet. Van den AKKER-SCHEEK et al. [10] showed that the normalized deviation of spatial and temporal gait parameters was significantly higher in patients with coxarthrosis than in healthy elderly subjects.

Gait variability can be examined during the walk along a walkway at any preferred self-selected walking speed (PSW) [6], [9]. A disadvantage is that – due to the limited length of the walkway – only the data on 5–10 steps can be recorded and analysed. More recent studies [3]–[5] included treadmill tests for the analysis of more steps performed at a self-selected walking speed. A simplified gait analysis determined the kinetic parameters and the temporal and spatial parameters of gait from the ground reaction force in the function of time during constant-speed gait on an instrumented treadmill. A simplified gait analysis can be carried out not only for few gait cycles but also for a number of gait cycles, and the motion of the upper and lower limbs does not hide the markers, the motion is more comfortable. Our previous research revealed that the average of spatial and temporal parameters depends on age, sports, and different orthopaedical diseases [11]–[13]. The goal of this research was to determine and compare the variabilities of spatial and temporal gait parameters in different healthy subjects, such as young, older and professional athletes, and in patients after meniscectomy and with hip osteoarthritis.

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2. Subject and method

In our research, 45 healthy, young subjects, 11 professional hand ball players, 24 patients after medial meniscectomy, 20 elderly, healthy subjects, and 20 patients with hip osteoarthritis were examined. The anthropometrical data of the subjects examined are summarized in table 1. *The subjects in the healthy groups* were without any clinical histories of diseases or injuries to the lower extremities. *The patients after meniscectomy* had bucket-handle tear in the posterior medial part of the meniscus. The part of the meniscus being excited was less than 30%. We did not find any ligament injuries, concomitant chondral lesions and signs of osteoarthritis. The time from injury to surgery was shorter than three months in the case of all patients. The symptoms of osteoarthritis were negative in all cases at the time of gait analysis. Gait analysis was performed 18 months after surgery. The average Harris Hip Score of *the patients with unilateral coxarthritis* was 51.3 points (±15.2), all patients had poor results (HHS < 70 points). All patients were seriously limited in their activities due to the pain.

Table 1. Anthropometrical data of subjects examined

Group	Number (male/female)	Age (years)	Height (cm)	Weight (kg)
Healthy young	23/22	24.2±9.1	169.4±3.1	68.12±15.6
Hand ball players	11/0	24.5±4.1	181.4±13.1	84.73.±8.9
Healthy elderly	8/12	68.8±9.2	169.1±19.6	73.36±11.4
Subjects after meninscectomy	13/11	29.6±4.7	168.8±9.8	70.31±9.9
Elderly with hip osteoarthritis	8/12	69.7±8.9	172.±11.3	70.16±9.2

The basic system consists of an instrumented treadmill ergometer (Kistler) with two built-in force plates; the treading area of 1500 mm × 500 mm has more than 5000 high-quality capacitive pressure/force sensors (figure 1). The instrument and the PC are linked via a USB interface. The zebris WINGAIT measuring program collects the vertical components of the ground reaction force during gait. The measuring frequency is 1000 Hz. Using a technology specially developed by ZEBRIS, the movement of the treadmill is compensated so that completely stable gait and roll-off patterns can be analyzed. The measurements were performed in the Biomechanical Laboratory of the Hospital of Hungarian Railways in Szolnok and in the Biomechanical Laboratory of the Department of Applied Mechanics at the Budapest University of Technology and Economics. Verification studies suggest that the method is reliable [14].

The subjects, in everyday clothes and without shoes, walked on a motorized treadmill (figure 1). In our research, the subjects walked at a constant speed of 2.5 km/h (not at a self-selected speed), because the walking speed significantly influenced the gait parameters [11]. Walking on the treadmill can initially be an unfamiliar experience. This in turn can influence the parameters measured. Therefore, the measurement starts after six-minute familiarization

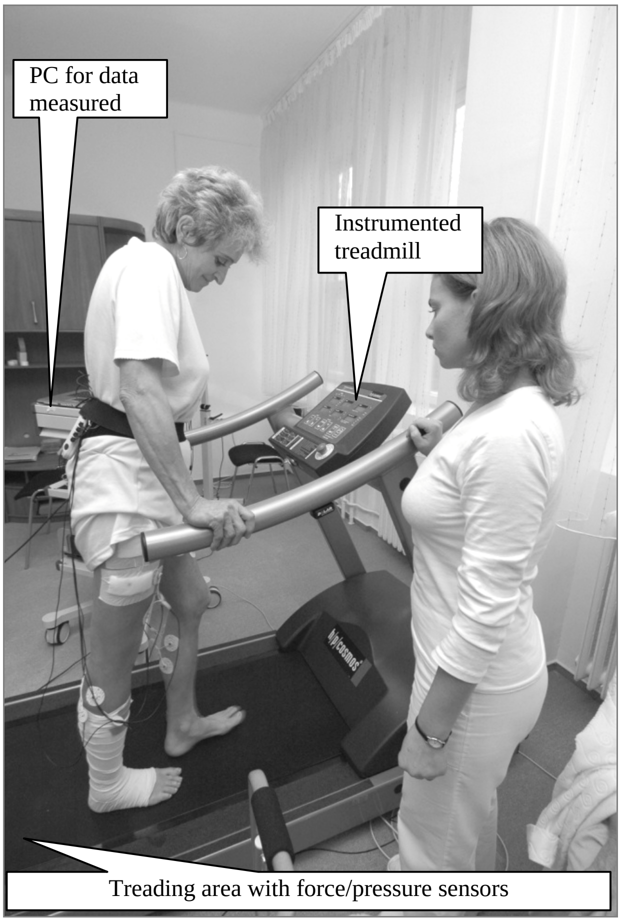

Fig. 1. Instruments for simplified gait analysis

time as suggested by ALTON et al. [15]. The measuring program collected the vertical components of the ground reaction force during at least fifty gait cycles.

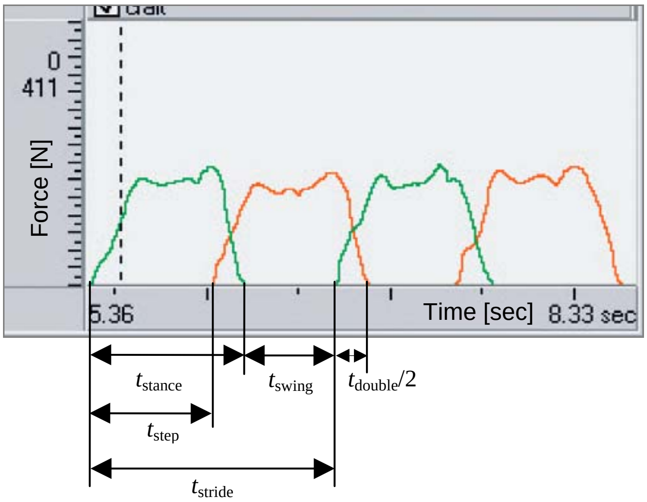

Fig. 2. Temporal parameters calculated from the graph of ground reaction force vs. time: t_{stance} – the length of stance phase (stance time) (s), t_{swing} – the length of swing phase (swing time) (s), t_{double} – the length of double support (s), t_{step} – the time of step (s), t_{stride} – the time of stride (s)

The tests were authorized by the Science and Research Ethics Committee of Semmelweis University. Each voluntary subject provided an informed written consent before performing the tests.

The temporal parameters such as the length of stance phase and the length of double support phase were calculated from the ground reaction force in the function of time (figure 2). The spatial parameters such as cadence and step length were calculated from temporal parameters and the constant gait speed [14].

For each subject, the average, standard deviation and normalized deviation (the proportion of standard deviation and the average) of the temporal and spatial parameters were determined based on 50 complete gait cycles. These data were further processed in order to calculate the average and standard deviation of the groups from the standard deviation and normalized deviation of the parameters of individuals.

All variable differences were tested for normal distribution using the Kolmogorov–Smirnov test and they all exhibited normal distribution. The overall comparison of gait patterns between the groups was made by ANOVA. Statistical significance was set at $p < 0.05$.

3. Results

For the sake of clarity, the results are summarized in tables 2 and 3 in average ±SD form. All subjects were able to walk 50 gait cycles on the treadmill at the speed of 2.5 km/h.

The deviation of spatial and temporal parameters of individuals can considerably be affected by the parameters' average value, therefore data evaluation is not objective (table 2). The normalized deviation introduced in order to eliminate differences is independent of the parameters' average value (table 3). No significant differences resulted from the comparison of the values of different parameters in each group (table 3). On the basis of our results the following conclusions can be drawn (table 3):

1. A comparison of the values of the dominant and non-dominant sides in healthy young, elderly subjects and in hand ball players did not reveal their significant differences.

Table 2. Average ±SD of the deviation of spatial-temporal parameters of individuals

Group	Length of stance phase (% of cycle)		Length of double support phase (% of cycle)	Cadence (step/minutes)	Step length (mm)	
	Dominant/ Healthy	Non-dominant/ Affected			Dominant/ Healthy	Non-dominant/ Affected
Healthy young	15.9 ± 0.05	14.4± 0.03	2.2± 0.02	10.7± 0.09	110.4± 0.35	110.0± 0.34
Hand ball players	11.0 ± 0.02	10.9± 0.03	1.2± 0.02	7.2± 0.07	91.7± 0.28	90.9± 0.25
Healthy elderly	15.0± 0.06	14.4± 0.05	4.9± 0.03	20.6± 0.13	114.4± 0.43	114.3± 0.44
Subjects after meninscectomy	15.6± 0.08	20.1± 0.10	3.0± 0.04	17.0± 0.19	112.6± 0.55	140.4± 0.63
Elderly with hip osteoarthritis	17.6± 0.10	22.0± 0.14	6.7± 0.03	37.0± 0.21	105.1± 0.46	125.6± 0.58

Table 3. Average ±SD of the normalized deviation of spatial-temporal parameters of individuals

Group	Length of stance phase (% of cycle)		Length of double support phase (% of cycle)	Cadence (step/minutes)	Step length (mm)	
	Dominant/ Healthy	Non-dominant/ Affected			Dominant/ Healthy	Non-dominant/ Affected
Healthy young	0.183 ± 0.004	0.182 ± 0.005	0.184 ± 0.003	0.181 ± 0.007	0.183 ± 0.002	0.182 ± 0.003
Hand ball players	0.144 ± 0.001^{+}	0.143 ± 0.003^{+}	0.142 ± 0.002^{+}	0.139 ± 0.003^{+}	0.142 ± 0.001^{+}	0.142 ± 0.004^{+}
Healthy elderly	0.234 ± 0.003^{+}	0.233 ± 0.002^{+}	0.233 ± 0.004^{+}	0.232 ± 0.005^{+}	0.232 ± 0.004^{+}	0.238 ± 0.002^{+}
Subjects after meninscectomy	0.201 ± 0.005$^{*,+}$	0.263 ± 0.006$^{*,+}$	0.261 ± 0.003^{+}	0.263 ± 0.006^{+}	0.204 ± 0.003$^{*,+}$	0.264 ± 0.005$^{*,+}$
Elderly with hip osteoarthritis	0.273 ± 0.002*,‡	0.347 ± 0.003*,‡	0.346 ± 0.005‡	0.349 ± 0.004‡	0.271 ± 0.005*,‡	0.351 ± 0.006*,‡

* Significant differences obtained comparing the sides.
$^{+}$ Significant differences compared to the healthy young group.
‡ Significant differences compared to the healthy elderly group.

2. Normalized deviation for hand ball players is significantly lower, and for elderly subjects it is significantly higher than that for healthy young subjects.

3. The normalized deviation of the non-affected side is significantly lower than that of the affected side. The normalized deviation of the both sides of patients is significantly higher than that of healthy young subjects.

4. The normalized deviation of the non-affected side is significantly lower than that of the affected side. The normalized deviation of the both sides of patients is significantly higher than that of healthy elderly subjects.

4. Discussion

A high number of gait cycles analyzed gives us opportunity to calculate the average and standard deviation and normalized deviation of different temporal and spatial parameters of each subject examined.

The normalized deviation of parameters enables modelling the variability of gait, because it is independent of parameter values due to normalization and of lateral dominance in healthy subjects (table 3). On the basis of our tests, it was established that there was no significant difference between the average values of temporal and spatial parameters of healthy subjects (table 3) either, which also testifies to the independence of the normalized deviation of parameters of lateral dominance. These results confirm to the conclusions from previous research [16], [17].

The value of the normalized deviation for professional athletes is significantly smaller than that of healthy age-matched non-professional athletes (table 3). The variability of spatial and temporal parameters characterizes the step-by-step reiterative accuracy of the motion of lower limbs [8], [18]. If the gait is automatic and rhythmic, then coordinated lower limb motions are repeated regularly, with slight step-by-step deviations (kinematic variability is low) [19], [20]. The lower variability of professional athletes confirms the assumption that sports develop static and dynamic perception and increase the stability of gait.

Kinematic variability represents an index of gait stability [19], and the increased variability of the spatial and temporal parameters [18], [19], [21] may indicate the instability of gait, that is, an increased risk of falling.

The value of the normalized deviation in healthy elderly subjects is significantly higher than that in healthy young persons (table 3), which correlates with the previous results [4]–[9]. The value of the normalized deviation in patients after meniscectomy at both sides is higher than that in healthy age-matched persons (table 3). MCNICHOLAS [23] assumes that the reduced spatial-temporal parameters and a decreased range of knee motion are caused by increased instability [23], as our results demonstrated. The value of the normalized deviation in patients with coxarthrosis at both sides is higher than that in healthy age-matched persons, which is similar to the results reported by van den AKKER-SCHEEK et al. [10]. An increased variability of the temporal and spatial gait parameters indicated an increased risk of falls and showed an increased instability during the gait of patients after meniscectomy, in subjects belonging to the healthy elderly group and in patients with coxarthrosis.

In conclusion, the simplified gait analysis method can be used for describing the spatial and temporal parameters of a number of gait cycles. Our tests show that the normalized deviation is independent of lateral dominance in healthy subjects. Our data proves that the variability of gait parameters greatly dependes on age, on the intensity of sports activities, and on orthopaedical diseases.

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