Are electromyographic patterns during gait related to abnormality level of the gait in patients with spastic cerebral palsy?

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Purpose: One of the aims of the treatment in ambulant cerebral palsy (CP) patients is improvement of gait. The level of gait pathology is assessed by instrumented gait analysis, including surface electromyography. The aim of this study was to investigate the relation of the abnormality level of the gait and the co-contraction of the agonist-antagonist muscles, and relation between symmetry left /right leg in gait and symmetry of muscular activity. *Methods*: Fifty one patients with cerebral palsy underwent clinical assessment and instrumented gait analysis, including surface electromyography. Signals were bilaterally collected from rectus femoris, medial and lateral hamstrings, tibialis anterior, lateral gastrocnemius and gluteus maximus. In older children additionally signals from soleus and lateral vastus were recorded. Sixteen gait variables were selected to calculate Gillette Gait Index, separately for left and right leg. From the envelopes a series of cross-correlation coefficients were calculated. *Results*: Weak correlations were found between averaged agonist-antagonist correlation coefficient and Gillette Gait Index. Differences between hemiparetic less-involved legs, hemiparetic spastic legs, and diplegic legs were found for co-contraction of rectus femoris and biceps femoris and for averaged agonist-antagonist co-contraction. The differences between hemiparetic and diplegic groups were found for some muscle correlation coefficients. *Conclusions*: The results obtained in this study show that the activity pattern of the leg muscles is specific to a given patient, and the dependence of the kinematics pathology on the abnormal activation pattern is not a direct one.

Key words: cerebral palsy, gait, EMG patterns

1. Introduction

Spastic cerebral palsy (CP) is one of the most common disorders of neurological origin among children and adolescents. It is caused by a lesion to immature brain, which occurs before, during, or just after the birth. This lesion does not change with time, but the resulting dysfunctions tend to worsen over time. Approximately 85 % of CP patients [3] suffer from spastic form of the disease, either hemiparesis, where one side is much more affected than the other, or diplegia, where both sides are more or less equally affected. The main problems of the CP patients are: abnormal gait pattern, muscular weakness, lack of selectivity, decreased muscular strength, coordination and balance problems [1]. The treatment options include rehabilitation treatment, anti-spastic drugs (i.e., botinum toxin injections), surgical orthopaedic treatment. The best results of the treatment could be achieved only if the choice of the treatment is based on the detailed knowledge about the type and level of patient's dysfunctions. As practically all ambulant CP patients encounter gait problems one of the main aims of the treatment is at least preservation or, better, improvement, of the gait pattern. One of the relatively widely used tools to determine the level of gait pathology is objective, instrumented gait analysis. Usually the collection of surface EMG signals is part of routinely done gait analysis, as these data can give the insight into the coordination and selectivity of the patient's muscles.

Several studies tried to use the surface EMG data collected during clinical gait analysis to supplement kinematics and kinetics to better understand the patient's functional problem. Wakeling and co-workers [8] used wavelet decomposition signals and principal component analysis to evaluate surface EMG. They found that EMG signals differ in timing, magnitude and frequency content from healthy controls. Zwaan et al. [11] used cross correlations between the envelopes of the averaged surface EMG signals. Cross correlation method proved that inter-session EMG patterns are characterized by very high repeatability between the trials [9]. Using this method Zwaan and co-workers investigated the "extensor synergy", i.e., the cross correlation between vastus medialis and gastrocnemius medialis, and "thigh synergy", i.e., the cross correlation between vastus medialis and semitendinosus. The team found high difference in these synergies between the CP patients and healthy controls, and quite high correlation between these synergies and clinical selectivity test. These results show that the EMG patterns during gait in patients with CP differ from the patterns in healthy controls. In the literature there is limited information about the relation between the abnormality of the EMG patterns and abnormality of the gait pattern. In the study done by van der Houven et al. [7] it was found that the botulinum toxin injections do not change muscle activation patterns, but in connection with intensive rehabilitation treatment lead to gait pattern improvement.

The aim of this study was to investigate the relation between the abnormality of the gait pattern and the co-contraction of the agonist-antagonist muscles (expressed as cross correlation of their envelopes), and to see if there is a dependence between symmetry between left and right leg in gait pattern and symmetry of muscular activity.

2. Material and methods

Patients

The group under investigation consisted of 51 patients with established (according to clinical criteria [1]) diagnosis of cerebral palsy. Twenty five of them were diagnosed with spastic diplegia, 26 with spastic hemiparesis (11 with left sided, 15 with right sided). The patients age ranged from 2 to 11.5 years (median age was 4 years). All patients were treated at the Department of Neurology, Epileptology and Paediatric Rehabilitation of The Children's Memorial Health Institute (CMHI). The data analysed in this study were collected at the first admittance of the patients to the rehabilitation program. All patients were walking independently. Some patients who fulfilled the inclusion criteria, but were not feeling safe in the laboratory environment were excluded from the study, thus out of over 70 patients only 51 were taken for the analysis. Patients who were treated previously by botulinum injections in other centres were excluded from the study. The study was approved by the Local Ethical Committee. Twenty patients had leg length discrepancy of 0.5 cm, in five patients the discrepancy was of 1 cm, in 4 of 1.5 cm, and finally in 2 the discrepancy attained 2 cm.

Methods

All patients underwent clinical assessment (including spasticity evaluation with modified Tardieu test, passive range of motion evaluation) and instrumented gait analysis as a routine evaluation of the Cerebral Palsy patients in CMHI. Instrumented gait analysis was performed using first VICON 460 6-camera motion analysis system (with sampling frequency 60 Hz), later using VICON MX 12-camera system (sampling frequency 100 Hz). In both systems the Plug-In-Gait model and marker set were used, and data were processed using Polygon software. The collection of data comprised kinematics, and surface EMG (sampling frequency was 1980 Hz in the case of older system, 2000 Hz in the case of new VICON system). Depending on the age (and body size) of the patients two protocols were used. For smaller (younger) children the signals were bilaterally collected from rectus femoris, medial hamstring, lateral hamstring, tibialis anterior, lateral head of the gastrocnemius and gluteus maximus. In older (and bigger) children additionally signals from soleus and lateral vastus were also recorded.

The purpose and details of the analysis was always explained to the patients. The markers and electrodes were mounted on them, and they were allowed to walk few times to get accustomed to the new environment. Six trials were collected for each patient, the data from these trials were averaged in the Polygon software. The data averages (expressed in per cent of the gait cycle) were later used for further evaluation. During the gait analysis patients were walking with their self-selected speed.

Kinematics

From kinematic and spatio-temporal data 16 variables were selected to calculate Gillette Gait Index

(GGI) [5]) Gillette Gait Index is one number, which expresses the distance of the patient's gait pattern from the gait pattern of healthy subjects. The index is separately calculated for left and right leg. Additionally, the ΔGGI was calculated as the difference between the GGI for the left and right leg.

EMG: The surface EMG signals were collected using 16 channel MA-300 EMG system (MotionLab-Systems, Inc. USA). The pre-amplified electrodes (non-gel) were placed over the muscles according to the SENIAM recommendations [10]. Two circular electrodes of 12 mm diameter (distance between them 17 mm) were separated by reference contact of 13 × 3 mm bar. Electrodes were produced from medical grade stainless steel. Amplification specifications were as follows: input impedance >100,000,000 Ohms, CMRR >100 dB at 65 Hz, noise <1.2 μV RMS, signal to noise ratio >50 dB, gain 20. The sampling frequency used was 1980 Hz while VICON 460 was used (video was sampled at 60 Hz), and 2000 Hz in the case of VICON MX system (video was sampled at 100 Hz). The EMG bandwidth was 10–2000 Hz.

Additionally the backpack to which the electrodes were plugged was grounded using single ground electrode. Before the electrode placement the skin was cleared using alcohol.

The envelopes were calculated using rectification of the signals and lowpass filtering at 5 Hz. Later the envelopes from several gait cycles of the same patients were averaged.

From the averaged EMG envelopes a series of cross correlation coefficients were calculated, similarly to the method described by Zwaan and co-workers [11]. As the assessment of antagonist and agonist muscles co-contractions the following correlations were calculated: between rectus femoris and lateral hamstring, rectus femoris and medial hamstring, and lateral gastrocnemius and tibialis anterior (for each leg). Later the coefficients were averaged as a reflection of overall expression of agonist-antagonist co-contraction. To assess the symmetry of the muscular work the correlation coefficients were calculated using envelopes of the right and left: rectus femoris, medial hamstring, lateral hamstring, tibialis anterior, and lateral gastrocnemius. Later the coefficients were averaged as an expression of an overall muscular symmetry.

Depending on the type of analysis the data of the whole patients' group were analysed together, the differences between hemiparetic and diplegic patients were checked, or the data obtained from less affected hemiparetic legs, more affected hemiparetic legs, diplegic legs were pooled together [2].

Statistical analysis

Due to non-normal distribution of the assessed variables the non-parametric tests were used. The correlations were calculated using Spearman rank correlation, the comparisons between two groups were done using Mann–Whitney test, and the comparisons between three groups were done using ANOVA Kruskal–Wallis test. The statistical significance was set on the level 0.05. All calculations were done using MedCalc software.

3. Results

1. Dependence between muscular agonist-antagonist co-contraction and gait pattern

No statistical significance between the GGI and the following coefficients was found: rectus femoris and lateral hamstrings, rectus femoris and medial hamstring, gastrocnemius and tibialis anterior. Weak statistically significant correlation was found between averaged agonist-antagonist correlation coefficient and GGI ($R = -0.294$). The results are presented in Fig. 1.
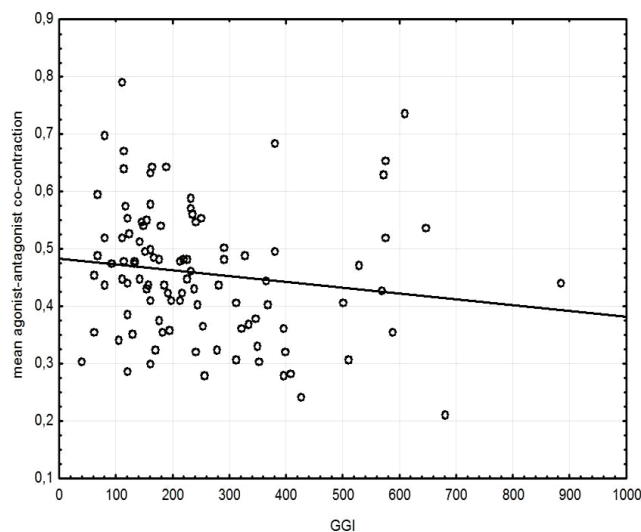

Fig. 1. The dependence between the Gillette Gait Index and the mean agonist-antagonist co-contraction correlation coefficient

2. Dependence of the gait pattern and agonist-antagonist co-contraction and type of the spastic dysfunction

The differences for agonist-antagonist correlation coefficients between three groups (less affected hemiparetic legs, more affected hemiparetic legs, and di-

plegic legs) were checked. The statistically significant differences were found for co-contraction of rectus femoris and biceps femoris ($H = 8.274$, $p = 0.016$) and for averaged agonist-antagonist co-contraction ($H = 10.303$, $p = 0.006$, Fig. 2).

In Table 1, the median, min and max values are summarised.

3. Symmetry of the muscular activity

No statistical significant correlation was found between ΔGGI and muscle correlation coefficients of rectus femoris, lateral hamstring, medial hamstring, tibialis anterior and gastrocnemius of left and right leg.

The differences between hemiparetic and diplegic groups were found for the following muscle correlation coefficients (expressing symmetry between left and right leg): gastrocnemius ($Z = -3.075$, $p = 0.002$), tibialis anterior ($Z = -3.027$, $p = 0.002$), medial hamstring ($Z = -2.202$, $p = 0.027$) and mean correlation ($Z = -3.318$, $p < 0.001$). The results are shown in Fig. 3, and given in Table 2.

4. Correlation between age, gait pattern and muscular activity

No statistical significant correlation was found between age, GGI, ΔGGI, and muscle correlation coefficients.
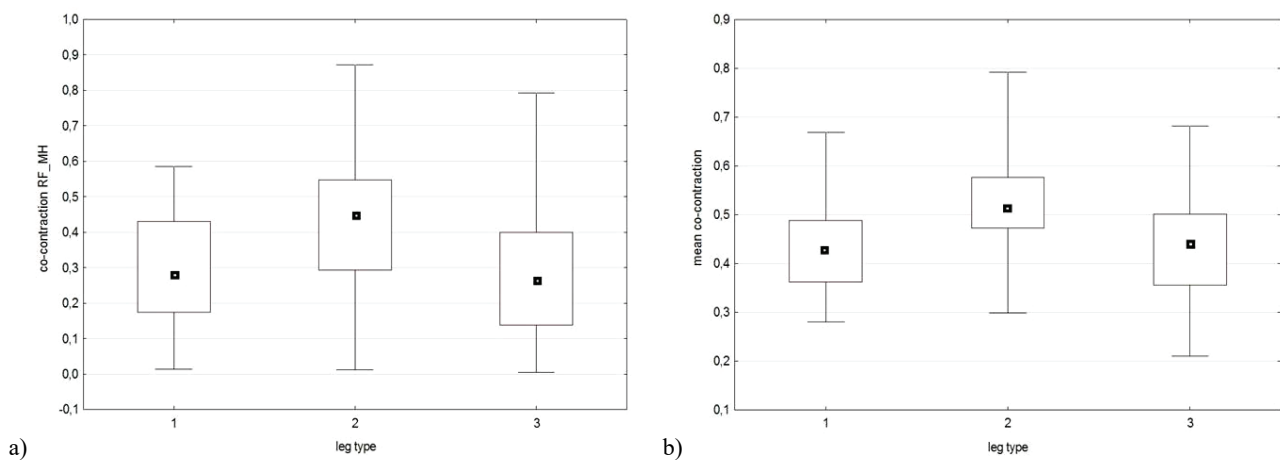

Fig. 2. The statistically significant differences between less affected legs (1), more affected hemiparetic legs (2) and diplegic legs (3) for co-contraction of rectus femoris and lateral hamstring (a) and mean agonist-antagonist co-contraction (b)

Table 1. The co-contraction correlation of rectus femoris and lateral hamstring, and mean co-contraction for less affected legs (1), more affected hemiparetic legs (2) and diplegic legs (3)

		RF_LH			Mean co-	Contr
	Median	Min	Max	Median	Min	Max
Group 1	0.280	0.014	0.586	0.430	0.280	0.669
Group 2	0.443	0.013	0.872	0.511	0.299	0.792
Group 3	0.260	0.005	0.793	0.438	0.210	0.623

Table 2. Means, min and max of the symmetry correlation coefficients for hemiplegic (H) and diplegic (D) group

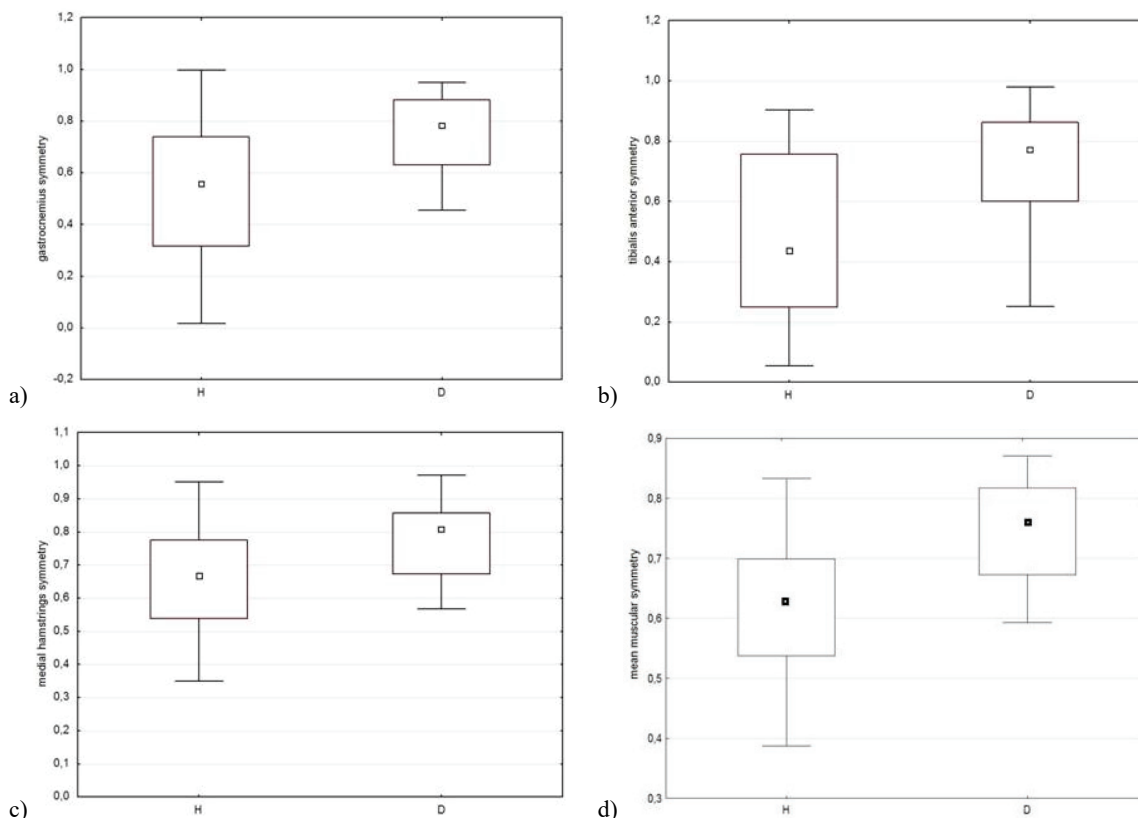|		H		D		
	Median	Mix	Max	Median	Min	Max
R-gastrocnemius	0.524	0.018	0.293	0.767	0.455	0.949
R-tibialis anterior	0.478	0.054	0.904	0.705	0.251	0.980
R-medial hamstring	0.627	0.145	0.951	0.732	0.451	0.971
R-mean	0.613	0.387	0.833	0.737	0.451	0.871

Fig. 3. The differences between hemiparetic (H) and diplegic (D) groups in muscular symmetry between left and right groups:
A: gastrocnemius, B: tibialis anterior, C: medial hamstring, D: mean correlation

4. Discussion

The results showed that there is weak correlation between mean agonist-antagonist co-contraction and the level of the gait dysfunction, expressed as Gillette Gait Index. Moreover, higher co-contraction is connected with lower GGI, i.e., better, closer to normal, gait pattern.

Mean agonist-antagonist co-contractions and rectus femoris and medial hamstrings co-contractions are similar in less affected hemiplegic legs, and diplegic legs, but in more affected hemiplegic legs they are much higher, suggesting that the lack of selectivity in hemplegic children on the more affected side could be even higher than in diplegic children.

There is no dependence between the ΔGGI (which reflects the asymmetry of the gait pattern between left and right side) and muscle correlation coefficients between the same muscles of the left and right leg.

The statistically significant differences were found between diplegic and hemiplegic patients in symmetry of muscular activity (muscle correlation coefficients

between the same muscles of the left and right leg) of the three muscles: medial hamstrings, gastrocnemius and tibialis anterior. The values of the correlation coefficients indicate that in diplegic patients the symmetry of the muscles' activity is higher than in hemiplegic patients. Although there is no statistical significance of ΔGGI between hemiplegic and diplegic patients the median value of ΔGGI for diplegic patients was 77.8 (range from 1.8 to 150.6), and for hemiplegic patients 105.2 (ranging from 3.5 to 436.1), which indicates more asymmetrical gait pattern in hemiplegic patients. The asymmetry of kinematics in hemiplegic patients (reflected by increased value of ΔGGI) is partly caused by the fact that hemiplegic patients exhibit compensatory movements on the less involved side.

The results obtained in this study show that the activity pattern of the leg muscles is specific to a given patient, and the dependence of the kinematics pathology on the abnormal activation pattern is not a direct one, although there are some well known dependences. For example, increased abnormal activity of the rectus femoris muscle in the swing phase limits the maximum knee flexion in swing, and increased activity of gastrocnemius

muscle in swing causes foot plantarflexion in this phase of gait. Generally calf muscles are thought to be the main contributors to the abnormal gait pattern, and their abnormal activity influences both ankle and knee joints [6].

Patikas and co-workers [4] found that the changes in muscular activity profiles after the multilevel surgical treatment occur to a much smaller extent than the changes which happend in kinematics. The changes observed were restricted to the shank muscles, while thigh muscles retained their activity pattern. Similar observation was done by van der Houven and co-workers [7]. Children with cerebral palsy who were treated with botulinum toxin injections improved their kinematics during gait, but the activation pattern of their muscles, investigated with surface EMG, remained unchanged. This is probably caused by the fact that muscular activity in paediatric patients is routinely registered by the surface electrodes, and by the systems with limited number of channels. Therefore nothing is known about most of the muscles responsible for the changes in kinematics of the lower limbs. Moreover, the kinematics of the pelvis and lower extremities is influenced by the movements of the trunk and upper extremities, which usually are not analysed.

5. Conclusion

The activity pattern of the leg muscles is specific to a given patient, and the dependence of the kinematics pathology on the abnormal activation pattern is not a direct one.

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