Gait asymmetry in Winters’ group I hemiplegic children

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Abstract— Hemiplegia is a neurological disorder that in children is a common consequence of cerebral palsy. Hemiplegia involves one-half of the body, while the other half is typically not affected. Aim of the study was to evaluate gait asymmetry in Winters’ group I hemiplegic children (W1), by identifying possible differences between hemiplegic and non-hemiplegic side in foot-floor contact and activation patterns of gastrocnemius lateralis (GL). To this aim, basographic and EMG data from 12 hemiplegic cerebral palsy children (Winters’ group I) were analyzed. Gait data from 100 normal developing children were used as reference. Mean decrease (p<0.05) of normal cycles (i.e. normal sequence of gait phases HFPS) and a concomitant increase (p<0.05) of atypical cycles (PFPS) were detected in hemiplegic side of W1, with respect to HFPS) and a concomitant increase (p<0.05) of atypical cycles (PFPS) were detected in hemiplegic side of W1, with respect to both non-hemiplegic side and control group. No relevant variations of GL recruitment were observed between hemiplegic and non-hemiplegic side of W1, in terms of muscle activation patterns and occurrence frequency. In conclusion, the study suggested that gait asymmetries detected in W1 lie in foot-floor contact patterns, but not in GL recruitment.

Keywords— cerebral palsy, hemiplegia, child walking, electromyography, statistical gait analysis.

I. INTRODUCTION

In children, hemiplegia is a common consequence of cerebral palsy and causes altered selective motor control, weakness and spasticity [1]. Hemiplegia is a neurological disorder that involves one-half of the body, while the other half is typically not affected. Thus, analysis of gait asymmetry in hemiplegic children can provide insight into the control of walking and may help in guiding the clinician’s treatment decisions. The gait pattern of children with hemiplegia was investigated by Winters et al. [2], describing the sagittal kinematic and electromyographic data of the hemiplegic side. A classification of spastic hemiplegia was also proposed [2]: Winters’ group I was defined by the presence of drop foot in swing in the hemiplegic side due to a hyper-activation of ankle dorsi-flexors. Winters’ group II is defined by the persistence of equinism throughout the gait cycle, with a possible knee hyperextension in stance. More recently, the dynamic EMG patterns of ankle muscles were analyzed to quantify the intra-subject variability in the hemiplegic side and to evaluate the percentage of occurrence of each pattern [3,4]. The variations reported in the hemiplegic side would be expected to cause related modifications on the recruitment at the non-hemiplegic limb. However, poor findings have been reported about the analysis of the uninvolved limb in hemiplegic children.

The aim of the present study was to evaluate gait asymmetry in Winters’ group I hemiplegic children, by quantifying the differences between hemiplegic and non-hemiplegic side in foot-floor contact patterns and in activation patterns of gastrocnemius lateralis (GL). In the hemiplegic side, no variations in the activity of plantar-flexors were detected in Winters’ group I, while a hyper-activation of gastrocnemius around initial contact arose with Winters’ group II [3]. The present study focused on GL to verify if also non-hemiplegic lower limb of Winters’ group I children is characterized by no alterations of plantar-flexors activity. This could be useful to further characterize Winters’ group I and improve the discrimination with group II.

II. MATERIALS AND METHODS

A. Subjects

Gait data were extracted from a retrospective study involving children with hemiplegia consequent to cerebral palsy. Children were referred to the Gait Analysis Laboratory of Santa Croce Hospital from 2005 to 2010. The research reported in this paper was undertaken in compliance with the ethical principles of the Helsinki Declaration and was approved by the local ethical committee. Parental consent and child assent were obtained. All gait and clinical examinations were performed by the same experienced physician. The Lab database was searched for children with Winters’ group I hemiplegia of age ranging from 5 to 13 years. Cases, which underwent previous lower limb orthopedic surgery or botulinum toxin injections in the six months preceding the gait examination, were excluded from the study. Two raters examined independently the video-recordings and kinematic data, and selected a total of 12 Winters’
group I children (W1, 5 females and 7 males) matching the inclusion criteria.

Gait data from 100 normal developing children (49 females and 51 males) were available from a previous study [5], and have been used as reference.

B. Instrumented gait analysis

Children were evaluated both with a clinical examination and with an instrumented gait examination performed with the multichannel recording system Step32, Medical Technology, Italy. They were equipped, bilaterally, with: a) foot-switches under the heel, the first and the fifth metatarsal heads and b) surface EMG electrodes positioned over the muscle’s belly of gastrocnemius lateralis (GL). Probes were positioned according to the guidelines suggested by Winter [6]. Children were instructed to walk at self-selected speed. They walked back and forth over a 10-m straight path and each acquisition lasted 150 s.

C. Foot-switch signal: the 4-level basography

From the 3 binary signals from the foot-switches a 4-level signal was extracted [7], corresponding to the following gait phases:

- Heel contact (H): only the foot-switch under the heel is closed.
- Flat foot contact (F): the foot-switch under the heel is closed and at least one of the foot-switches under the forefoot is also closed.
- Heel off or “push off” (P): the foot-switch under the heel is open and at least one of the foot-switches under the forefoot is closed.
- Swing (S): all foot-switches are open.

The signal was segmented into separate gait cycles and the algorithm described in [7] classified the different cycle types.

D. Foot-floor contact sequence

A subject typically uses different types of gait cycle while walking, each observable with a specific percentage of occurrence [7]. The more frequent sequence of foot-floor contact observed in control children was HFPS [8].

- HFPS: normal sequence of gait phases (heel contact, flat-foot contact, push-off, swing)

Cycles showing a different sequence of gait phases were called “atypical cycles” [7]. Most representative atypical cycles in hemiplegic patients were cycles initiating with the forefoot (P), instead of the heel. Among them, PFPS cycles were the most frequently observed. More specifically:

- PFPS: after initial forefoot contact (P), the heel also touches the ground — hence the entire foot is in contact with the ground (F) — then the heel raises for push-off (P), and swing follows (S).

E. Surface EMG signal

EMG signals were acquired (sampling rate: 2 kHz; resolution: 12 bit) and processed by the multichannel recording system, Step32 Medical Technology, Italy. EMG probes are constituted by Ag-disks (manufacturer: Medical Technology, diameter: 4 mm; interelectrode distance: 12 mm, gain: 1000, high-pass filter: 10 Hz, 2 poles). EMG signals were further amplified, band-pass filtered (20-450 Hz, 6 poles), and processed by a double-threshold statistical detector, allowing a user-independent assessment of muscle activation intervals [9].

F. Statistical Gait Analysis

Statistical gait analysis (SGA) [8,10] is a recent methodology, which performs a statistical characterization of gait by averaging spatial-temporal and sEMG-based parameters over an elevated number of strides, in the same walking trial. SGA relies on the fact that the number of muscle activations is cycle dependent, so that averaging should be performed only over onset/offset instants of cycles including the same number of activations, i.e. belonging to the same activation modality. Activation modality was defined as number of times a muscle activates during a single gait cycle (n-activation modality consists of n activation intervals for the considered muscle, during a single gait cycle). GLi (i=1−5) is the i-activation modality for GL. Mean activation intervals (normalized to gait cycle) for each activation modality were achieved, according to following steps.

- Muscle activation intervals relative to each gait cycle were identified, computing muscle onset/offset instants in temporal space, as previously described.
- Muscle activations were grouped according to their modality.
- Onset/offset time instants of each activation modality were averaged over the single subjects.
- Mean onset/offset time instants of each activation modality (computed in each single subject) were averaged over the whole population.
Occurrence frequency, defined as the frequency each muscle activation occurs with, quantified by the number of strides in which the muscle is recruited with that specific activation modality was also provided [11].

G. Statistics

Data were reported as mean ± standard error (SE). Shapiro-Wilk test was used to evaluate the normality of each distribution. ANOVA test and Kruskal-Wallis test were used to compare normally and not normally distributed samples, respectively. Statistical significance was set at 5%.

III. RESULTS AND DISCUSSION

Figure 1 shows with dark gray bars the relative frequency of the HFPS and PFPS foot-floor contact patterns observed for W1 in the hemiplegic side while for the non-affected limb light gray bars are used. Same data were reported for the control group as reference for “normality” (white bars). HFPS sequence was observed in hemiplegic side of W1 (dark gray bar) in 28% of strides. This percentage was significantly (p<0.05) lower than in non-hemiplegic side of W1 (79%, light gray bar) and in control group (90%, white bar). In hemiplegic side of W1 (dark gray bar), PFPS sequence was detected in 47% of strides. This percentage was significantly (p<0.05) higher than in non-hemiplegic side of W1 (7.6%, light gray bar) and in control group (4.5%, white bar). These findings indicated that W1 children adopted modified foot-floor contact patterns mainly in the hemiplegic side.

Muscle activation patterns are reported in Figure 2. Cycles where GL showed 1 (GL1), 2 (GL2) or 3 (GL3) activations during gait cycle, were considered separately. Cycles with more activations were not considered, since statistically not relevant.

For each group, only gait cycles associated to the most frequent foot-floor contact sequence were reported: HFPS for controls (white) and non-hemiplegic side of pathological children (light gray) and HFPS and PFPS for hemiplegic side of pathological children (dark gray). Muscle activation intervals followed roughly the typical pattern during child walking [5,8,12]. In hemiplegic children (both hemiplegic and non-hemiplegic side), muscles showed different modalities in number of activations and timing of signal onset/offset, in different strides of the same walking, as in control group (Figure 2). Small differences were detected in activation intervals among populations (Figure 2).

Fig. 1 Different foot-floor contact sequences (% of total strides) in control children (white bars) and in non-hemiplegic (light gray bars) and hemiplegic (dark gray bars) sides of Winters’ type I hemiplegic children (mean and standard error are displayed for each population). * significantly different from the other two mean values.

Fig. 2 Mean (+SE) activation intervals vs. percentage of gait cycle for gastrocnemius lateralis for control children (white), non-hemiplegic side of pathological children (light gray) and for hemiplegic side of pathological children (dark gray). Cycles where GL showed 1 (GL1), 2 (GL2) or 3 (GL3) activations during gait cycle were reported in Panel A, B, and C, respectively.
However, only the early OFF for second PFPS activation in hemiplegic side of pathological children in Figure 2, panel C was statistically significant (p<0.05). Despite this, the ON/OFF instants were similar among populations, indicating the absence of relevant variation of muscular recruitment between hemiplegic and non-hemiplegic side of W1 for gastrocnemius lateralis.

Occurrence frequencies of muscle recruitment are reported in Figure 3. No significant differences were detected among population for all the activation modalities. This finding confirmed the absence of relevant variation of GL recruitment between hemiplegic and non-hemiplegic side of W1 children for gastrocnemius lateralis.

IV. CONCLUSION

The study suggested that detected asymmetries in hemiplegic children walking (Winters’ group I) lie in foot-floor contact patterns, but not in GL recruitment. This outcome could be useful to further characterize Winters’ group I and improve the discrimination with group II, where hyper-activation of gastrocnemius in hemiplegic side was detected. Dynamic EMG data could be useful for the study of walking (a)symmetry of the single hemiplegic child, helping to provide a personalized approach to patient’s care. In particular, the pattern percentage-of-occurrence may be used to quantify how often a child exploits a specific gait pattern, and to what extent this pattern is representative of his/her gait. Studies on further muscles (tibialis anterior [13]) are evoked, because stepping on the forefoot (in PFPS) may originate from insufficient activation of tibialis anterior.

CONFLICT OF INTEREST

Authors declare that they have no conflict of interest.

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