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Full Length Article

Analysis of gait patterns pre- and post- Single Event Multilevel Surgery in children with Cerebral Palsy by means of Offset-Wise Movement Analysis Profile and Linear Fit Method

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ABSTRACT

Gait analysis is used for the assessment of walking ability of children with cerebral palsy (CP), to inform clinical decision making and to quantify changes after treatment. To simplify gait analysis interpretation and to quantify deviations from normality, some quantitative synthetic descriptors were developed over the years, such as the Movement Analysis Profile (MAP) and the Linear Fit Method (LFM), but their interpretation is not always straightforward.

The aims of this work were to: (i) study gait changes, by means of synthetic descriptors, in children with CP that underwent Single Event Multilevel Surgery; (ii) compare the MAP and the LFM on these patients; (iii) design a new index that may overcome the limitations of the previous methods, i.e. the lack of information about the direction of deviation or its source.

Gait analysis exams of 10 children with CP, pre- and post-surgery, were collected and MAP and LFM were computed. A new index was designed as a modified version of the MAP by separating out changes in offset (named OC-MAP).

MAP documented an improvement in the gait pattern after surgery. The highest effect was observed for the knee flexion/extension angle. However, a worsening was observed as an increase in anterior pelvic tilt. An important source of gait deviation was recognized in the offset between observed tracks and reference. OC-MAP allowed the assessment of the offset component versus the shape component of deviation.

LFM provided results similar to OC-MAP offset analysis but could not be considered reliable due to intrinsic limitations. As offset in gait features played an important role in gait deviation, OC-MAP synthetic analysis was proposed as a novel approach to a meaningful parameterisation of global deviations in gait patterns of subjects with CP and gait changes after treatment.

Abbreviations: GA, gait analysis; SD, standard deviation; RoM, Range of Motion; RMS, root mean square; CP, Cerebral Palsy; GDI, Gait Deviation Index; GPS, Gait Profile Score; GVS, Gait Variable Score; LFM, Linear Fit Method; MAP, Movement Analysis Profile; MCID, Minimally Clinical Important Difference for GPS; OC-GPS, Offset Corrected - Gait Profile Score; OC-GVS, Offset Corrected - Gait Variable Score; OC-MAP, Offset Corrected - Movement Analysis Profile; R, Pearson's coefficient of correlation; SEMLS, Single Event Multilevel Surgery; TD, typically developing children

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1. Introduction

Gait analysis (GA) is a multifactorial and powerful tool that provides a quantitative description of normal and pathological gait patterns. It is therefore widely adopted as a routine exam in specialized clinical centres (Carriero, Zavatsky, Stebbins, Theologis, & Shefelbine, 2009; Whittle, 1996). For instance, clinical GA was used to characterize: Parkinson's disease (Sale et al., 2013), Down syndrome (Galli, Rigoldi, Brunner, Virji-Babul, & Giorgio, 2008), and Cerebral Palsy (CP) (Carriero et al., 2009; van den Noort, Ferrari, Cutti, Becher, & Harlaar, 2013) and it was used to validate novel treatments (Camerota et al., 2015; Sale et al., 2013; Vismara et al., 2016). GA was proved useful especially to aid the selection of optimal treatment in the case of spastic Cerebral Palsy (CP), which may involve different kinds of motor disorders and therefore different gait patterns (Galli, Cimolin, Rigoldi, Tenore, & Albertini, 2010; Piccinini et al., 2011). Moreover, GA allowed the quantification of changes in gait patterns of subjects with CP after treatment such as surgery (Galli, Cimolin, Crivellini, & Albertini, 2009).

GA exams usually consist of the integration of data from different sources, namely: kinematic data, kinetic data, video recording, electromyography, etc. Thus, a single GA exam contains a large volume of data that is processed into a high dimensional space of parameters, such as spatiotemporal parameters, joint/segment angles, forces, moments, etc. All these parameters are usually presented in the form of a clinical report, i.e. a collection of tracks (the time evolution of a variable as a function of the gait cycle) and numerical parameters (Stebbins et al., 2014; Whittle, 1996). A gait report can be difficult to understand and requires specific training of the clinicians. So the need to represent gait by means of a reduced number of parameters (e.g. a classification) emerged. Many studies focused on the validation of synthetic descriptors that could classify the severity of a pathological gait pattern by quantifying the deviation from a normality range. Such synthetic numbers are useful for treatment follow up evaluation or to study the natural evolution of the gait pattern over time (Galli, Cimolin, De Pandis, Schwartz, & Albertini, 2012).

A recently proposed and widely used index is the Gait Deviation Index (GDI) (Schwartz & Rozumalski, 2008). It is an overall, dimensionless, multivariate and comprehensive index that provides an overall measure of gait quality (Esbjörnsson et al., 2014). It was applied to children with CP (Cimolin, Galli, Vimercati, & Albertini, 2011; Molloy, McDowell, Kerr, & Cosgrove, 2010), showing a good repeatability, with an uncertainty of ± 10% (Massaad, Assi, Skalli, & Ghanem, 2014). Moreover, the GDI was successfully used to quantify gait deviations in subjects with Parkinson's disease (Galli et al., 2012) and rheumatoid arthritis (Esbjörnsson et al., 2014).

The main limitation of GDI is that, even though it is useful to assess the overall gait pattern, being a single number, it is inherently not informative on the location of the impairment (Massaad et al., 2014). This limitation was addressed by a related method, i.e. the Movement Analysis Profile (MAP) (Baker et al., 2009). The MAP is based on the computation of a deviation index, named "Gait Variable Score" (GVS), for nine relevant kinematic variables (joint angles). The GVSs quantify the deviation from normality for each gait feature and they can be averaged into an overall index, named "Gait Profile Score" (GPS). GPS was shown to be strongly correlated to GDI (Baker et al., 2009).

Validity studies showed a GPS Minimally Clinical Important Difference (MCID), i.e. 1.6° (Baker et al., 2012), while several studies were conducted about GPS reliability when applied to subjects with pathology. E.g. GPS was used to study gait deviation in subjects with Ehlers-Danlos Syndrome (Celletti et al., 2013), concluding that the GPS and MAP are appropriate for the evaluation of functional gait limitation in these patients. GPS was also used for the characterization of gait in children with CP and other neurological/orthopaedic disorders (Beynon, McGinley, Dobson, & Baker, 2010). Results showed a good correlation with other qualitative ratings of kinematic gait deviation. The effects of orthopaedic interventions on gait in children with CP were studied by Rutz, Donath, Tirosh, Graham, and Baker (2013), finding a pre-operative GPS of 15.5° ± 3.9° that reduced to 11.2° ± 2.5° post orthopaedic intervention. They observed that the degree of improvement was higher in the patients with the worst initial conditions. GPS score was demonstrated of being correlated to the strength of the subject and it was observed that gait kinematics grossly depended on muscle strength (Schweizer, Romkes, Coslovsky, & Brunner, 2014). This finding confirmed that muscle strength influences stability of ligaments and quality of the motor performance in general (Ancillao, Rossi, & Cappa, 2017). Gait performance was also influenced by cognitive load and dual task activities in subjects with Parkinson's Disease and the GPS was able to detect changes in gait, changing from 9.17° ± 1.18° of the "normal gait" condition to 10.30° ± 1.37° of the "dual task" condition (Speciali et al., 2014). Another study investigated the walking characteristics in individuals with Multiple Sclerosis, concluding that the single measure of GPS can characterize gait kinematics of such patients (GPS = 9.12° ± 2.28°). Moreover a correlation between GPS and the "Expanded Disability Status Scale" was observed (Pau et al., 2014). Strong correlation between GPS and clinicians' ratings was also previously observed by (Beynon et al., 2010).

Even though the MAP allows to localize the anatomical joint or segment whose pattern deviates from normality, it is still limited in describing which is the nature of the deviation, e.g. the offset between curves, the scaling factor or a time-shift. Identifying the source of deviation is clinically important as it allows to more precisely identify which kind of limitation is affecting gait. E.g. crouch gait, that involves persistent knee flexion, is mainly characterized by an offset in knee flex/ext tracks. Changes in gait patterns, due to surgical procedures, are often observed as changes in the offset of some gait features (Sutherland & Davids, 1993). Thus more detailed synthetic descriptors, which take into account the offset and quantify its effects, are likely to be more informative to the clinical user.

A different approach to compare gait features to reference data was proposed by Iosa et al. (2014). The method allows to assess similarity between the observed waveform and reference GA tracks, in terms of shape, amplitude and offset. It consists of the application of a Linear Fit Method (LFM) to two time-normalized datasets. The result of the LFM are: (i) the R^2 regression coefficient, that quantifies the strength of relationship between the tracks; (ii) the $a0$ coefficient, i.e. the constant term of polynomial regression that represents the scalar addition (shift or offset) between the compared datasets; (iii) the $a1$ coefficient, i.e. the first coefficient of first order polynomial regression that represents the amplitude scaling factor. When LFM is used to compare a GA exam to a control group, the R^2, $a0$, and $a1$, parameters can be assumed as synthetic descriptors of deviance from normality. Anyway, it was proved that