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A gait index may underestimate changes of gait: a comparison of the Movement Deviation Profile and the Gait Deviation Index

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The ability of the Movement Deviation Profile (MDP) and Gait Deviation Index (GDI) to detect gait changes was compared in a child with cerebral palsy who underwent game training. Conventional gait analysis showed that sagittal plane angles became mirrored about normality after training. Despite considerable gait changes, the GDI showed minimal change, while the MDP detected a difference equal to a shift between 10-9 on the Functional Assessment Questionnaire scale. Responses of the GDI and MDP were examined during a synthetic transition of the patient's curves from before intervention to a state mirrored about normality. The GDI showed a symmetric response on the two opposite sides of normality but the neural network based MDP gave an asymmetric response reflecting faithfully the unequal biomechanical consequences of joint angle changes. In conclusion, the MDP can detect altered gait even if the changes are missed by the GDI.

Keywords: cerebral palsy; virtual rehabilitation; self-organising map; artificial neural network; MDP; GDI

1. Introduction

Flyvbjerg (2006), in a discussion of the various uses of single case studies, cites Karl Popper's famous example of the black swan which as a single contrary instance falsifies the proposition that 'all swans are white'. When evaluating the gait of a child, we found an unexpected discrepancy between the Movement Deviation Profile (MDP) and the Gait Deviation Index (GDI), which otherwise show an excellent match when evaluating thousands of cases. This single anomaly motivated a forensic comparison of the two methods.

Gait indices are single numbers used to express the deviation of an individual's gait from normal gait (Schutte et al. 2000; Schwartz and Rozumalski 2008; Baker et al. 2009; Barton et al. 2012). The GDI is the transformed, scaled and standardised Euclidean distance of a patient from the mean of controls in a 15 dimensional gait feature space (Schwartz and Rozumalski 2008). It is derived from singular value decomposition of nine gait angle curves of a large number of patients and controls. An alternative index, $\mathrm{MDP}_{\mathrm{mean}}$, is derived from the more generic MDP (Barton et al. 2012), which is a single curve showing the deviation of an individual's movement from normal at each sample along the movement. Simultaneous multi-channel time series (e.g. gait angle curves) describing movement of a group of controls are used to train a self-organising map (SOM, Kohonen 2001), which stores a representation of the characteristics of normal movement in the network's weights. From this, the deviation profile of a patient's movement can be derived. The $\mathrm{MDP}_{\mathrm{mean}}$ is calculated as the mean of the series of unsigned movement deviation values, and like the GDI it provides a single number.

Demonstrating concurrent validity of the GDI, MDP and other gait indices involved comparing the gait indices of patients with independent measures of function, e.g. Functional Assessment Questionnaire (FAQ) or Gross Motor Function Classification System scores (Schwartz and Rozumalski 2008; Baker et al. 2009; Molloy et al. 2010; Barton et al. 2012). Although statistically significant differences were found between most neighbouring functional categories, the typical clinical use of gait indices is to test if an individual patient's gait moves closer to normal as a result of intervention. In an earlier study (Barton et al. 2011), a single patient played a virtual reality game intended to improve core control and was evaluated by clinical gait analysis before and after the intervention. The aim of this study was to compare the findings of the clinical gait analysis with changes in the GDI and MDP.

2. Methods

One boy with cerebral palsy diplegia (age 10 years; height 1.34 m; mass 36 kg) trained for 6 weeks, twice a week, for 30 min in each session on our custom-made 'Goblin Post Office' computer game, developed in the CAREN system (Motek Medical, Amsterdam, the Netherlands). The motions of two clusters of three reflective markers, each forming a triangle, attached to the pelvis and trunk, respectively, were used to navigate a flying dragon along a cave to collect envelopes hovering at seemingly random positions (Barton

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3.4 Behaviour of the MDP method with a simplified data-set

In this patient, the majority of joint angle changes occurred in the sagittal plane. So that a 3D visualisation of the favourable response characteristics of the MDP was possible, a reduced subset of three joint angles was selected. The sagittal plane hip, knee and ankle angles of the original 166 TD controls were used to train a new SOM consisting of a 2D lattice of 27 × 17 nodes. After training, the SOM was used as before to find a series of best matching units (BMUs), which are positioned closest to the series of 3D data points on the normality lattice. This was performed with the two sets of equivalent gait data from the patient and a 3D-MDP was derived for each set. Figure 4 shows the position of the patient's three joint angles as a 3D curve in relation to the SOM lattice before intervention, after intervention and for the pre-intervention angles mirrored about $\mathrm{TD}_{\mathrm{average}}$. This example illustrates how the SOM (underlying the MDP) finds the nearest trajectory on the normality lattice, and so its algorithm does not contain any steps which would restrict its output to be symmetrical on the two sides of $\mathrm{TD}_{\mathrm{average}}$ as is the case with the GDI.

3.5 Visualisation of the nearest path of normality next to the MDP

The full set of nine gait curves requires a data space of nine dimensions, in fact the MDP can handle data of any dimensionality, but the SOM lattice in SOM space is typically 2D. The set of BMUs on the SOM lattice provides additional information about the MDP's characteristics. A multi-dimensional trajectory representing an altered set of joint angles may be positioned at the same mean distance ($\mathrm{MDP}_{\mathrm{mean}}$) from normality as its precursor, but this is likely to be with reference to an altered set of BMUs in the SOM. For example in the full 9D problem, the $\mathrm{MDP}_{\mathrm{mean}}$ of the patient before intervention was 20.8° but the same value occurs at 176% along the hypothetical curve showing the transition of the patient towards and beyond $\mathrm{TD}_{\mathrm{average}}$ (see diamond on Figure 3). Even though the $\mathrm{MDP}_{\mathrm{mean}}$ is identical, the whole MDP curve shows the distances referenced to a different path of BMUs on the normality lattice (Figure 4(c)). An altered sequence of BMUs indicates that the altered data have changed its multi-dimensional position relative to normality even if its mean distance to normality has not changed. The latest version of the MDP program (Figure 5) now includes a graph of the SOM lattice and the sequence of BMUs.

4. Conclusions

The patient's gait changed symmetrically about $\mathrm{TD}_{\mathrm{average}}$ in the sagittal plane and this has exposed the inability of the GDI to differentiate between equal deviations on the opposite sides of $\mathrm{TD}_{\mathrm{average}}$. In response to the symmetrical change of gait, the $\mathrm{MDP}_{\mathrm{mean}}$ indicated an increased deviation from normality in agreement with the conventional analysis. Mathematical manipulation of the patient's curves towards $\mathrm{TD}_{\mathrm{average}}$ confirmed further that the $\mathrm{MDP}_{\mathrm{mean}}$ approaches its most normal value in a mathematically well-behaved manner as opposed to the GDI which soars to infinity. While the MDP is based on Euclidean distance just like the GDI, it finds the closest series of locations on the normality hypersurface. As a result even if the $\mathrm{MDP}_{\mathrm{mean}}$ is the same, the reference normality may be different. Visualisation of the best matching sequence of normality is now included in the freely available MDP 3.0 program as an electronic addendum.

To complement the advantages of the GDI, additional use of other gait indices not based on RMSD (e.g. MDP) is recommended. Together with examination of the original gait data, a more faithful evaluation of the patient's gait is expected.

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