ORIGINAL ARTICLE

GAIT PATTERN RECOGNITION IN CEREBRAL PALSY PATIENTS USING NEURAL NETWORK MODELLING

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Background: Interpretation of gait data obtained from modern 3D gait analysis is a challenging and time consuming task. The aim of this study was to create neural network models which can recognise the gait patterns from pre- and post-treatment and the normal ones. Neural network is a method which works on the principle of learning from experience and then uses the obtained knowledge to predict the unknowns. **Methods**: Twenty-eight patients with cerebral palsy were recruited as subjects whose gait was analysed in pre and post-treatment. A group of twenty-six normal subjects also participated in this study as control group. All subjects' gait was analysed using Vicon Nexus® to obtain the gait parameters and kinetic and kinematic parameters of hip, knee and ankle joints in three planes of both limbs. The gait data was used as input to create neural network models. A total of approximately 300 trials were split into 70% and 30% to train and test the models, respectively. Different models were built using different parameters. The gait modes were categorised as three patterns, i.e., normal, pre- and post-treatments. **Results**: The results showed that the models using all parameters or using the joint angles and moments could predict the gait patterns with approximately 95% accuracy. Some of the models e.g., the models using joint power and moments, had lower rate in recognition of gait patterns with approximately 70–90% successful ratio. **Conclusion**: Neural network models can be used in clinical practice to recognise the gait pattern for cerebral palsy patients.

Keywords: Neural Network, Cerebral Palsy, Gait Analysis, Kinetics, Kinematics.

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INTRODUCTION

Cerebral palsy (CP) is caused by injury to the brain during birth and has multiple effects on the body characterised mainly by abnormal motor tone, resulting in spasticity causing hemiplegia, diplegia or quadriplegia. An abnormal walking pattern is the result of imbalance in muscle tone between agonists and antagonists groups, contractures and deformities. The natural history is a gradual decrease in the mobility and range of motion of different joints, affecting the lower limbs more than the upper limbs, and worsening of the major determinants of gait. A classical and widely used definition of CP, reported by Bax in 1964 and suggested by an international working group, was "a disorder of movement and posture due to a defect or lesion of the immature brain".[1]

3D gait analysis has changed the shape of treatment of CP greatly. It has a vital role not only in pre-treatment assessment and decision making but also in accurate assessment of the outcome after post treatment. The addition of gate analysis data resulted in changes in surgical recommendations in over 50% of the patients.[2] Gait analysis is an essential tool in the management of cerebral palsy and allowing complete assessment of gait abnormalities both pre- and post-treatment has radically changed the management of cerebral palsy patients.[3] Gait analysis is now accepted as pre-treatment assessment of CP patients.[4] De Luca *et al*. (1997) compared the surgical recommendations made by experienced clinicians on the basis of their clinical examination with recommendations made after computerised gait analysis and electromyography (EMG) which showed alterations in recommendations in 52% of patients.[5]

Gait analysis and joint parameters provide useful clinical information and the gait pattern is given in the form of multiple curves; however, there are many joint parameters and so many curves which pose a great difficulty for the clinicians in decision making, as to which parameters and curves to rely upon, from the data obtained. Manual detection of gait events via visual inspection of motion capture data is a laborious process but it is essentially a classification problem and neural networks are well suited for that.[6] Miller concluded that once trained, the neural network model is autonomous, accommodative of any gait pattern and speed and time saving. Hersh *et al*. (1997) used neural networks to predict the post-operative gait pattern in diplegic CP patients who had bilateral rectus transfers to the sartorius. They concluded that the neural network can be generalised and be a reliable predictor for new patients.[7]

Kaczmarczyk *et al* used neural networks to classify gait in post-stroke patients and compared three methods of classification and found that neural networks was the best. They concluded the artificial neural network to be far superior method in classifying the gait pattern in post-stroke patients.[8]

In previous studies the application of neural network was combined with other tools e.g. electromyography (EMG) or conventional methods of gait classification and NN was trained mostly on two groups of gait pattern. An attempt has been made to address this by recruiting pre- and post-treatment gait patterns of CP patients in both treatment modalities (injection & surgery) and also the normal gait pattern. This mix of gait patterns is important for NN to predict with higher accuracy and when trained on different gait patterns, it can predict any unknown gait pattern with great success. The aim of this study was to create models using neural network modelling to predict gait patterns from the normal and CP.

MATERIAL AND METHODS

This study was conducted at Institute of Motion Analysis and Research (IMAR), Ninewells Hospital and Medical School, University of Dundee, United Kingdom. Gait analysis data from both pre- and post-treatment of 28 cerebral palsy patients and gait analysis data of 26 normal subjects was extracted from the existing database of approximately 300 patients after ethical approval for this study.

Group of normal subjects comprised of 26 subjects of which 21 were male. Average age of normal subjects was 12 years with a range of 9–16 years. The injection group was comprised of 13 patients out of whom 7 were males. Average age was 9 years with a range of 5–38 years. The surgery group comprised of 16 patients out of which 10 were males. The average age was 13 years and the range was 5–36 years.

The existing database of 300 patients was explored and 40 patients were selected initially who fulfilled the criteria of selection for this study: who had pre and post-treatment gait analysis, were ambulant and who had treatment either in the form of injection, surgery or both.

The electronic data of gait analysis of the recruited subjects was retrieved from the database using Vicon Polygon® software. Three best trials were chosen for each subject from the many pre- and post-treatment sessions. The gait cycle of heal strike, foot off and heal strike again was marked for each trial.

Joint angles, force, power, moments from hip, knee and ankle (with maxim, minimum and range) in three planes and walking parameters e.g. speed, swing, stride length, cadence and stance ratio were used.

Three groups were created for this study: (1) Injection group: consisted of 13 subjects, (2) Surgery group: consisted of 16 subjects and, (3) Normal Subjects group: consisted of 26 subjects. The pre- and post-treatment sessions for injection and surgery groups were identified in the Vicon Nexus® and the best dynamic trials for both pre- and post-treatment were selected. Three trials were chosen for most of the subjects except a few who had less than three most suitable trials for this study.

The selected trials were opened in Vicon Nexus® and reconstruction was done to visualise the markers and label them appropriately by attaching Plug-In-Gait® model. The labelled markers were then processed to produce digital stick diagram. Heel strike of one foot followed by toe off and heel strike again of the same foot were marked manually in the gait cycle for each foot. The defined gait cycle and processed data of the trials for each subject were saved and exported to excel files by pipeline function. This data was then processed further by the in-house software and used for creating models using neural networks function of SPSS.

Figure-1 shows the schematic functional layout of the neural networks. The input is in the form of parameters, the hidden layer in the middle and output layer which is the results (prediction).

RESULTS

Summary of the results has provided for all the models in injection and surgical groups, in Tables 1 and 2. The summary tables give the mean (avg), standard deviation (stdev), maximum (max) and minimum (min) for all the models in both groups.

The models created using all parameters in both injection and surgical groups produced the high quality results, both being over 95% correct in training samples and over 90% correct in testing samples, respectively. The models created using kinetic only (force, power & moment) parameters in injection group and model created using angles and gait parameters in surgical group, yielded approximately 95% correct results in training samples and 90% in testing samples. Similarly, another model in surgical group created using joint angles and gait parameters predicted with 95% and 90% accuracy in training and testing samples, respectively.

On the other hand, as can be seen from the summary (Tables-1 and 2), models created using angles and power and using important parameters only produced less accurate results, both being less than 90% accurate in training and testing samples.
The figures-1 and 2 show the ROC curves for the representative models (out of many) created using all parameters in both injection and surgical groups.

This model was created using all kinetic and kinematic parameters for hip, knee and ankle joints of the both lower limbs, in three planes (x, y, z). The recognition of gait pattern in the training sample was 100% correct and the predicted results in the testing sample were 96.8% correct in this representative model. Figure-3 shows the results in the form of ROC curve. This model was created using all the available parameters of kinetics and kinematics for hip, knee and ankle joints in three planes (x, y, z) of both lower limbs.

Model has predicted with 100% accuracy for all sub-groups both in training and testing samples except 1 out of 9 (pre-surgical) in the testing sample. The training sample as can be seen from the tables shows 100% correct predictions and the testing sample shows over 98% correct predictions. The pre-surgical category of testing sample was less than just under 90%, meaning only 1 out of 9 was predicted incorrectly. The ROC curve (Figure-3) shows the corresponding results, 1 being maximum (100%).

Table-1: Summary of results of injection group models

Model	Training Prediction %				Testing Prediction %			
	Mean	SD	Max	Min	Mean	SD	Max	Min
All parameters	98	2.5	100	87.6	92.9	3.3	100	86.8
Kinetic	94.8	4.54	100	83.3	89.9	4.3	100	83.7
Angles+Gait	89.4	6.14	99.2	79.3	85.6	4.5	95.5	71.4
Important	87.5	5	96.3	78.1	82.4	6	90.5	71.4

Table-2: Summary of results of surgical group models

Model	Training Prediction %				Testing Prediction%			
	Mean	SD	Max	Min	Mean	SD	Max	Min
All Parameters	97.62	2.51	100	82.1	90.64	3.77	100	82.1
Angles & Moments	96.61	3.24	100	87.7	91.25	4.08	97.7	87.3
Angles & Power	87.86	7.65	98.4	74.8	85.11	5.7	93.6	72.9
Angles & Gait	94.82	3.83	99.2	87.2	89.98	3.26	96.2	84.8

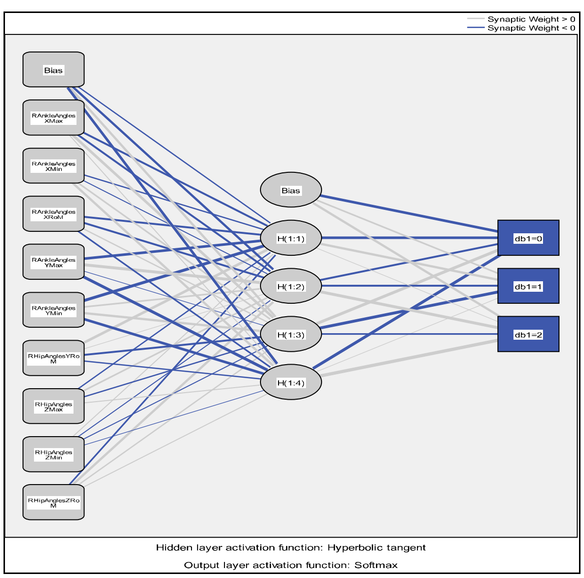

Figure-1: Functional layout of Neural Networks

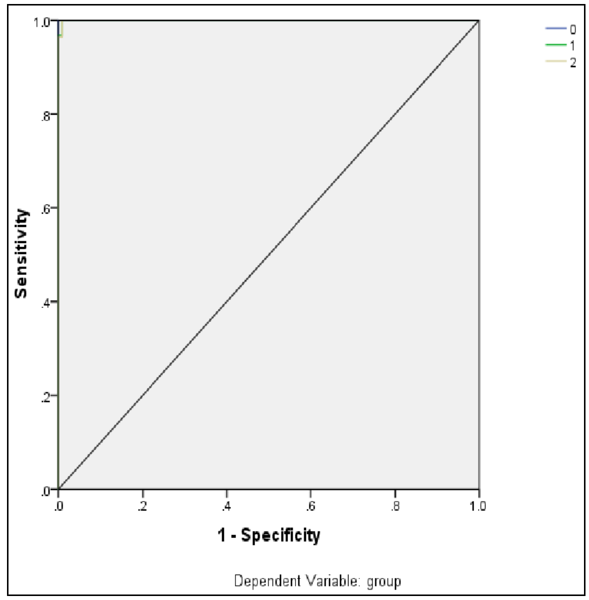

Figure-2: ROC Curve for a representative model of Injection group Model created using of all Parameters

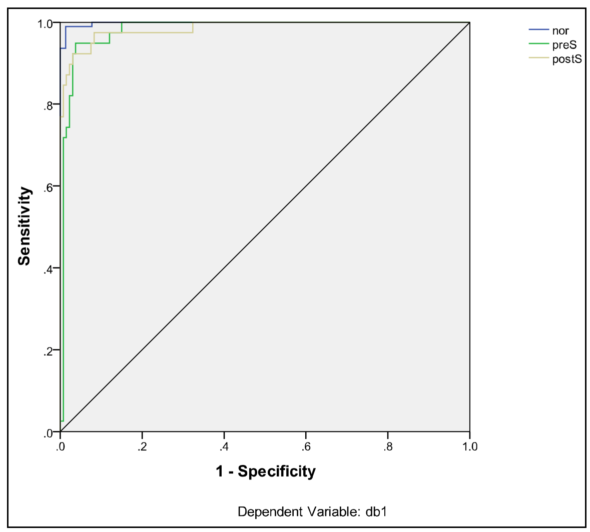

Figure-3: ROC Curve for a representative model

DISCUSSION

The purpose of this study was to create models using neural network (NN) which can assess the gait analysis (GA) and differentiate the gait patterns in Cerebral Palsy (CP) patients' pre-treatment and post-treatment gait and by doing so, help decision making.

We can summarise that the neural network has predicted with great accuracy in most of the models, particularly, in training samples and the results in testing samples in most of the models in both categories, on average have been over 90% correct. The models with all parameters and some of the combinations for example, joint angles and joint moments, kinetic parameters alone (in injection group) and kinematic parameters with gait parameters, produced high quality of results.

On the other hand, some of the models, e.g., using joint power and joint angles or using important parameters produced less accurate results, although some of these models are reasonable. On the basis of our findings in these models, we would not recommend them to use for decision making purposes.

To the best of our knowledge, there is no previous study in the literature related to the application of NN for gait pattern recognition in different groups, e.g. pre- and post- treated CP patients involving both the modalities of treatment, injection and surgery combined with the normal subjects.

In previous studies, the neural networks have been used by various researchers to classify the gait pattern with varying rates of success. Barton and Lee studied by using hip and knee joint angles.[9] Their work was on normal, adducted and abducted foot and they were able to classify the gait pattern with a rate of 77–100% using NN models.

Holzreiter and Kohle used artificial neural network to classify the abnormal gait by measuring ground reaction force to distinguish the gait pattern of normal and pathological individuals with a success rate of approximately 95%.[10]

Miller[4] studied gait event detection in the pathological subjects using neural network. To train the model in his retrospective study, he used the motion capture and force plate data. Foot-contact and foot-off from the gait cycle was chosen from the walking trials of the CP patient data, to train the model. In this study, heel-strike to heel, toe off and heel strike again has been used to define the gait cycle. The network used in Miller's study was single hidden layer and feed forward, as the one we used in our study. The results were compared with the force plate detection method and he found the neural network model to be robust and versatile.

Kaczmarczyk *et al* used neural networks to classify gait in post-stroke patients and compared three methods of classification and found neural networks to be the best with success rate of 85–100%.[8] Their study was based on full progression of joint angle changes in two planes only- frontal and sagittal planes. They compared the neural network with qualitative test with 85% success rate and with analysis of min/max angle values in lower limb joints with least success rate of less than 50%.

This study provides a variety of models with various different combinations of parameters and most of the models are able to predict with a great accuracy.

The major shortcoming is that the gait data were not easy to collect, as the information on data collection was not matched with the patient records. Also, the data quality of gait analysis had a great impact on the output or performance of the neural networks. Some of the values for GA were missing and therefore, some walking trials had to be excluded from the study.

There are 2 ways to apply the models produced here in other centres of clinical gait analysis. One way is to export the models as XML files, then the other users will need to use SmartScore and SPSS Statistics Server (2 other products of the IBM) to apply the model information to other data files for analysis of gait pattern. The other way is to create similar models using the methods introduced here.

CONCLUSION

In this study, the NN have been applied in a variety of ways using different combinations of parameters as well as all the kinetic and kinematic and gait parameters. The results have extremely high rate of accuracy in most of the models created in this study. Some of these models are able to predict with 100% accuracy both in the training samples and testing samples. The model using joint angles and gait parameters and the model using kinetic parameters only are examples with overall 95% of successful results. The models using all parameters are also able to predict with accuracy of 95%. We can conclude that the neural network modelling is a robust and a very accurate method of interpretation of gait analysis.

Although the results of this study confirm the significant usefulness of the neural networks models it is suggested that future studies need to test the models using more specific groups with further division of their gait pattern and mode of treatment.

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AUTHOR'S CONTRIBUTION

WW: Designed project; JM, SG, RA, WW: collected data; JM and WW: analysed data; JM and WW modelling and statistics; JM and WW writing up, SA: critically reviewed the manuscript and proof read.

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