COMPARISON OF VALIDATION TECHNIQUES FOR NEURAL NETWORK ESTIMATION OF JOINT MOMENTS DURING GAIT

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INTRODUCTION

Full, three-dimensional gait analysis provides clinically useful measures of normal and abnormal gait patterns. However, costly equipment is a limitation for many clinical settings. A few studies have demonstrated that artificial neural networks (ANN) can accurately map nonlinear relationships between electromyography (EMG) signals and joint torque (Hahn, 2005; Koike and Kawato, 1995; Luh et al., 1999). Only one previous study has estimated lower extremity joint moments from surface EMG (Sepulveda et al., 1993), however current efforts in our laboratory are showing initial success in estimating joint moments during gait using similar ANN models.

The focus of this study was to compare a k-fold cross validation technique within the ANN to the bootstrap re-sampling used previously. K-fold cross validation has become a widely accepted model validation technique because of its ability to reduce computational time (Burman, 1989). Implementing this technique should decrease processing time of the ANNs used in joint moment estimation models, making them more useable in clinical settings.

METHODS

A three layer feed-forward ANN designed during prior research (Hahn, 2005) was implemented in this study using the Neural Network Toolbox in Matlab 7.0 (The Mathworks, Inc.). The data used for training and testing the ANN were compiled from nineteen subjects (12 female, 7 male; 22.3 ± 1.6 years). All subjects completed a brief survey regarding physical activity and joint health, allowing screening for neuromuscular or orthopedic pathologies prior to participation.

Each subject performed a series of gait trials at their self-selected pace. Lower limb trajectories were sampled at 200Hz using Workstation® software (ViconPeak, Lake Forest, CA). An AMTI platform was used to collect the ground reaction force data, sampled at 1000Hz. EMG signals were recorded at 1000Hz using a Myopac Jr. (Run Technologies, Inc., Mission Viejo, CA) and passive surface electrodes on seven muscles (gluteus maximus, gluteus medius, biceps femoris, rectus femoris, vastus lateralis, tibialis anterior and medial gastrocnemius).

Seventy-seven total trials (approximately 4 trials per subject) were entered into the ANN for analysis. Analysis involved comparing two different techniques of validation: bootstrap re-sampling and 11-fold cross validation (CV). Each technique was used three times for each joint.

The inputs of the neural network included subject demographics and anthropometrics as well as the kinematic and EMG data. The target, or output layer, was the time-normalized joint moments of the hip, knee, and ankle. The training goal was 0.1 mean-square error between the actual joint moment and the target. Five processing units were used in the hidden layer for mapping
between the input and output. Back-propagated error correction was performed using the Levenberg-Marquardt algorithm.

Bootstrap re-sampling was performed by first randomizing the dataset according to trial, followed by training and testing of the ANN. A proportion equal to 0.7 of the data was selected to train the ANN while the remaining data was used for testing. This process was repeated fifty times to ensure broad re-sampling of trials selected for training and testing.

The 11-fold CV technique also began with randomizing the data according to trial. The data was then divided into eleven equal subsets. Ten of the subsets were used to train the ANN while the sole remaining subset was used to test the neural network. This process was repeated until each of the eleven subsets was used for testing.

For each joint, total processing time was recorded for each validation technique. Correlation coefficients as well as the mean number of epochs to reach the output goal were also recorded. A two-sample t-test assuming equal variance was performed to test mean number of epochs and mean correlation coefficients for significant effect of validation technique (α=0.05).

RESULTS AND DISCUSSION

The 11-fold CV performed faster with comparable accuracy compared to bootstrapping. For the ankle joint, the average processing time for 11-fold CV was 29.36 seconds whereas bootstrapping took 110.69 seconds. Processing for the knee and hip joints took longer than the ankle. However, the 11-fold CV still performed 2.76 times faster than bootstrapping for the knee joint and 3.1 times faster for the hip (Table 1).

The difference in correlation coefficients between the two re-sampling techniques was not significant for the ankle or the knee. The hip model however, showed a significantly improved accuracy with 11-fold CV. The difference between epochs needed was not significant for any of the joints (Table 1).

SUMMARY/CONCLUSIONS

Processing time of the ANN decreased considerably using the 11-fold CV technique while no significant difference was found for training epochs required or prediction accuracy for the ankle and knee. The present ANN model has shown initial success in estimating joint moments during gait. However, faster processing times will benefit the clinical application of this model.

REFERENCES


Table 1: Results for each of the two validation techniques; Mean value given.

<table>
<thead>
<tr>
<th></th>
<th>ANKLE</th>
<th>KNEE</th>
<th>HIP</th>
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<tbody>
<tr>
<td>Technique</td>
<td>Epoch</td>
<td>R</td>
<td>Time (s)</td>
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<tr>
<td>11-fold</td>
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<tr>
<td>Bottstrapping</td>
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* significant technique effect