

# ESTIMATION OF JOINT MOMENTS DURING GAIT USING NEURAL NETWORKS

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## INTRODUCTION

A number of studies have used surface electromyography (EMG) with Hill-based models to estimate joint forces and moments during gait (Hof et al, 1987; Olney and Winter, 1985; Bogey et al., 2005). Currently, these models are not well applied in the general clinical environment, specifically in rural settings, perhaps due to expense and space requirement of key equipment and the need for specially-trained technical staff. A model is needed for joint moment estimation which would facilitate the application of current joint dynamics research in general clinical practice. The purpose of this study was to develop a model for estimating joint moments of the hip, knee and ankle during normal gait using easily measured gait descriptors as model input. A set of artificial neural networks (ANNs) were used for this purpose.

## METHODS

Nineteen healthy young adults (12 female / 7 male; 22.3yrs, 173.7cm, 72.0kg) performed a series of walking trials at self-selected speed. Muscle activation was recorded using passive surface EMG collected at 1000Hz from the gluteus medius, gluteus maximus, biceps femoris, rectus femoris, vastus lateralis, medial gastrocnemius, and tibialis anterior using the Myopac Jr. (Run Technologies, Inc., Mission Viejo, CA). EMG signals were bandwidth filtered (10-1,000Hz), full wave rectified and enveloped with a 4<sup>th</sup> order Butterworth filter (low pass cutoff = 5Hz). Processed EMG signals were normalized for

each gait cycle to the maximal activation occurring within that cycle.

Three-dimensional marker trajectory data were collected at 200Hz using a six-camera digital capture system (Vicon 460; ViconPeak, Inc., Lake Forest, CA), and smoothed using Woltring filtering (MSE = 30). Virtual marker positions were estimated to represent internal segment endpoints from the external markers, and the relative positions of the segmental centers of mass based on the Plug-In Gait software (ViconPeak).

Ground reaction force data were synchronized with the motion capture and collected at 1000Hz using two force platforms (AMTI, Watertown, MA) embedded into the walkway. The center of pressure position was computed for each stance foot based on the three measured components of the resultant GRF and three components of the moment about the origin of the force platform. Three-dimensional resultant joint moments were then calculated for the ankle, knee and hip using the inverse dynamics approach.

Three unique 3-layer ANNs (one each for hip, knee, ankle) were designed to estimate joint moments for every point of a time-normalized gait cycle. The input layer consisted of subject-specific demographic (age, gender) and anthropometric data (body height, body mass, segmental moments of inertia), normalized/filtered EMG, and joint kinematics (position, velocity, acceleration). The middle layer consisted of a variable number of hidden units (5 – 30). The output

layer contained one unit representing joint moment data. Back-propagated error correction was conducted with a Levenberg-Marquardt algorithm. Training data proportion was set to 0.7, and the training error goal was tested for settings of 0.1 and 0.01. The ANNs were trained until the error goal was met, or until 1000 epochs. Bootstrap re-sampling (50 training attempts) was used for model validation.

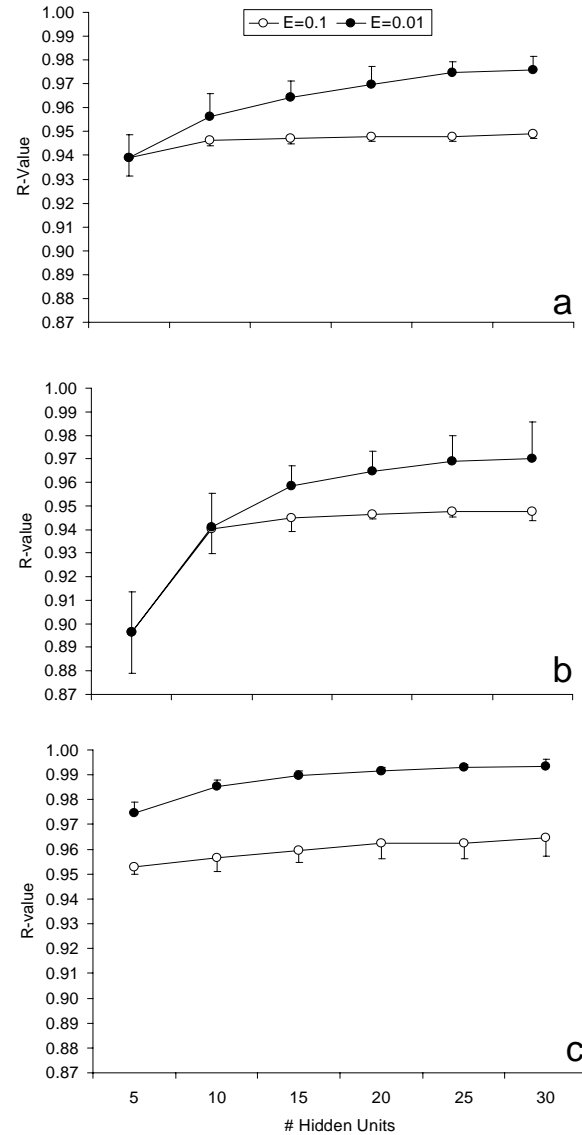
## RESULTS AND DISCUSSION

With all complete trials from each subject, over 7,500 cases were entered for ANN training/testing. Results were promising, with joint moment prediction reaching R-values greater than 0.94 for the hip, knee and ankle when the error goal was set at 0.1., and greater than 0.97 when the error goal was set to 0.01 (Figure 1). Increasing the number of hidden units resulted in greater model accuracy, especially with an error goal of 0.01.

ANN training time (# of epochs) increased to the point of non-convergence for all joint models when the error goal was 0.01 (Table 1). This indicates that while producing highly fit training sessions, the end results may not be as accurate when generalized to a broader population.

## SUMMARY/CONCLUSIONS

These results show initial success in estimating joint moments during gait with ANN models. Further validation of these model estimates will involve time domain analysis of case-specific outcomes in laboratory and clinical settings.



**Figure 1:** Correlation coefficients of the hip (a), knee (b) and ankle (c) models.

## REFERENCES

- Bogey, R.A. et al. (2005) *IEEE Trans Neural Syst Rehabil Eng*, **13**, 302-310.  
Hof, A.L. et al. (1987). *J Biomech*, **20**, 167-178.  
Olney, S.J., Winter, D.A. (1985) *J Biomech*, **18**, 9-20.

**Table 1:** ANN training time for hidden units of 10, 20 and 30; Mean epochs.

Error Goal	Hip			Knee			Ankle		
	10	20	30	10	20	30	10	20	30
<b>0.1</b>	240	15	12	696	37	46	7	7	6
<b>0.01</b>	1000	1000	1000	998	1000	1000	1000	1000	463