NEURAL NETWORK USED FOR THE PREDICTION OF JOINT TORQUE FROM GROUND REACTION FORCE DURING COUNTER-MOVEMENT JUMP AND SQUAT JUMP

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The purpose of this study was to develop an artificial neural network (ANN) for predicting the joint torque of lower limb using solely the ground reaction force (GRF) parameters for counter-movement jump (CMJ) and squat jump (SJ). Ten sport students performed CMJ and SJ on force plate, meanwhile the kinematic data were recorded and the joint torque were calculated as experimental data by inverse dynamics. We used a fully-connected, feed-forward network comprised of one input layer, one hidden layer and one output layer trained by back propagation using Steepest Descent Method. The input parameters of ANN were relevant time variables of GRF measurement and the output parameters were joint torque. The results revealed that the ANN model fitted the experimental data well indicating that the model developed in this study is feasible in the assessment of joint torque for CMJ and SJ.

KEY WORDS: artificial neural network, joint torque, GRF, CMJ, SJ

INTRODUCTION: The measurement of ground reaction force (GRF) during vertical jump was often used to assess the athlete's muscular strength and power of lower limbs (Bosco, 1999). However, the GRF could only specify the muscular power ability of lower limbs in general. It could not reflect the muscle joint torque and the neuromuscular control ability at each joint of lower limbs. From biomechanical point of view, human limb motions are caused and controlled by joint torque, and therefore it gives information about the neural control mechanisms (Zernicke, 1996). In order to obtain the information of the joint torque, three things must be done, namely synchronously measurement of the motion kinematics and the GRF, inverse dynamics calculation by inputting the kinematic data, GRF data and the anthropometric parameter (Robertson et al., 2004). The purpose of this study was to develop an artificial neural network (ANN) model for predicting the joint torque at ankle, knee and hip using solely the relevant parameters of GRF during counter-movement jump (CMJ) and squat jump (SJ).

METHODS: 10 male sport students (age: 20.10 ± 1.91 yrs; height: 179.34 ± 4.25 cm; weight: 69.58 ± 3.91 kg) were served as subjects. They performed counter-movement-jump (CMJ) and squat jump (SJ) on a Kistler force platform (1200 Hz). Meanwhile, the kinematic data of CMJ and SJ were recorded synchronously and digitized with a Peak Performance System at 120 Hz. The joint torque at ankle, knee and hip were calculated as experimental data by inverse dynamics through inputting the GRF, kinematic data and Dempster's body segment parameters (Robertson et al., 2004).

In this study, we used a fully-connected, feed-forward network comprised of one input layer, one hidden layer and one output layer trained by back propagation using Gradient Steepest Descent Method (Schalkaff, 1997). The input parameters of the ANN model were time variables obtained by the GRF measurement during the support phase of CMJ and SJ using the software of Kistler force-platform. These were time percentage (t%), GRF ($F_y(t)$), vertical displacement of center of mass (c.m.)(Y(t)), vertical speed of c.m. ($V_y(t)$) and power (P(t)). The power was defined by $F_y(t)$ times $V_y(t)$. The output parameters of the model were time data of joint torque at ankle (T_a), knee (T_k) and hip (T_h) (Figure 1). Since the movement times are different among subjects, all input and output parameters were normalized as 100% of support phase, meanwhile the input variables were scaled and the output variables were rescaled before and after running the ANN. The root mean square (RMS) error of prediction was employed to measure the network fitness. The Software PCNeuron 4.1 was used for developing the ANN model in this study.

RESULTS: The data of nine subjects were chosen randomly for modeling and training of the ANN. The rest one subject was used as test sample to measure the network fitness. After trial-and-error optimization procedure, a "5-10-3 ANN model" was development in present study, in which there were 5 neurons in the input layer, 10 neurons (nodes) in the hidden layer and 3 neurons in the output layer (Figure 1). Sensitivity analysis of the numbers of node (neuron) in hidden layer during the learning and testing phases demonstrated that the choice of numbers of hidden node was not critical, which was in agreement with the study of Luh et al (1999).

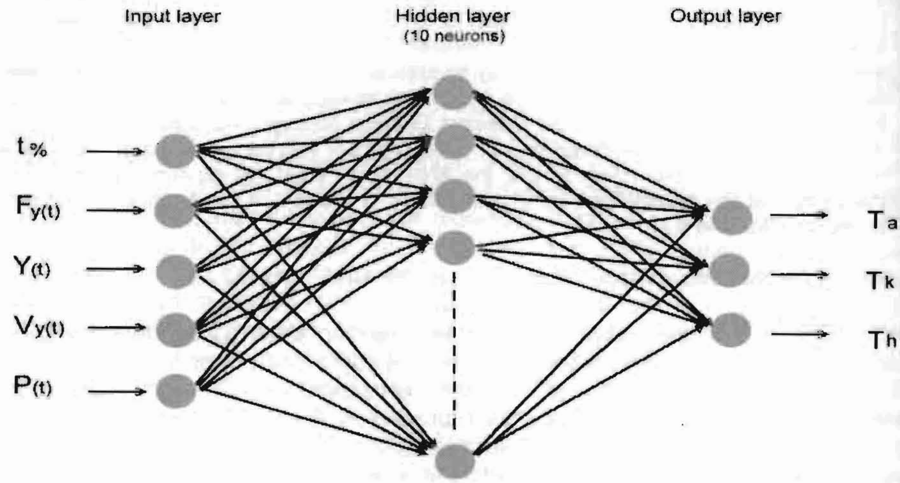

Figure 1 ANN model with 5 neurons in the input layer, 10 neurons (nodes) in the hidden layer and 3 neurons in the output layer.

The joint torque at ankle, knee and hip during CMJ and SJ obtained by the inverse dynamics calculation (Measured Torque) and by the ANN model using GRF (Predicted Torque) are displayed in Figure 2. The results indicate that there was a high level of agreement between the ANN predictions and the experimental data.

Table 1 shows the measured and predicted peak joint torque, the relative errors between them and the correlation coefficient between the measured and the predicted time curves of joint torque at ankle, knee and hip for CMJ and SJ. The peak values of joint torque were normalized by subject's body weight. The results demonstrate that, compare to the measured torque, the relative errors of the predicted peak joint torque at three joints for both CMJ and SJ were less than 8% by using ANN. Except the joint torque at knee for SJ, the relative errors for all rest joints were smaller than 5%. The predicted and the measured time curves of joint torque were also significantly correlated, the correlation coefficients were greater than 0.95 for both CMJ and CMJ at all joints.

Table 1 The peak values of measured and predicted joint torque, the relative errors (the percentage differences between the measured and the predicted peak torque) and the correlation coefficient between the measured and the predicted time curve of joint torque at ankle, knee and hip for CMJ and SJ. (: $p < 0.01$).**

Joint	Peak Torque Measured [Nm/kg]		Peak Torque Predicted [Nm/kg]		Relative Error [%]		R (n=100)	
	CMJ	SJ	CMJ	SJ	CMJ	SJ	CMJ	SJ
Ankle	-1.908	-1.970	-1.938	-2.085	1.56	5.84	0.967**	0.978**
Knee	+1.882	+1.488	+1.972	+1.606	4.78	7.93	0.987**	0.977**
Hip	-2.459	-2.051	-2.359	-1.983	4.06	3.31	0.979**	0.957**

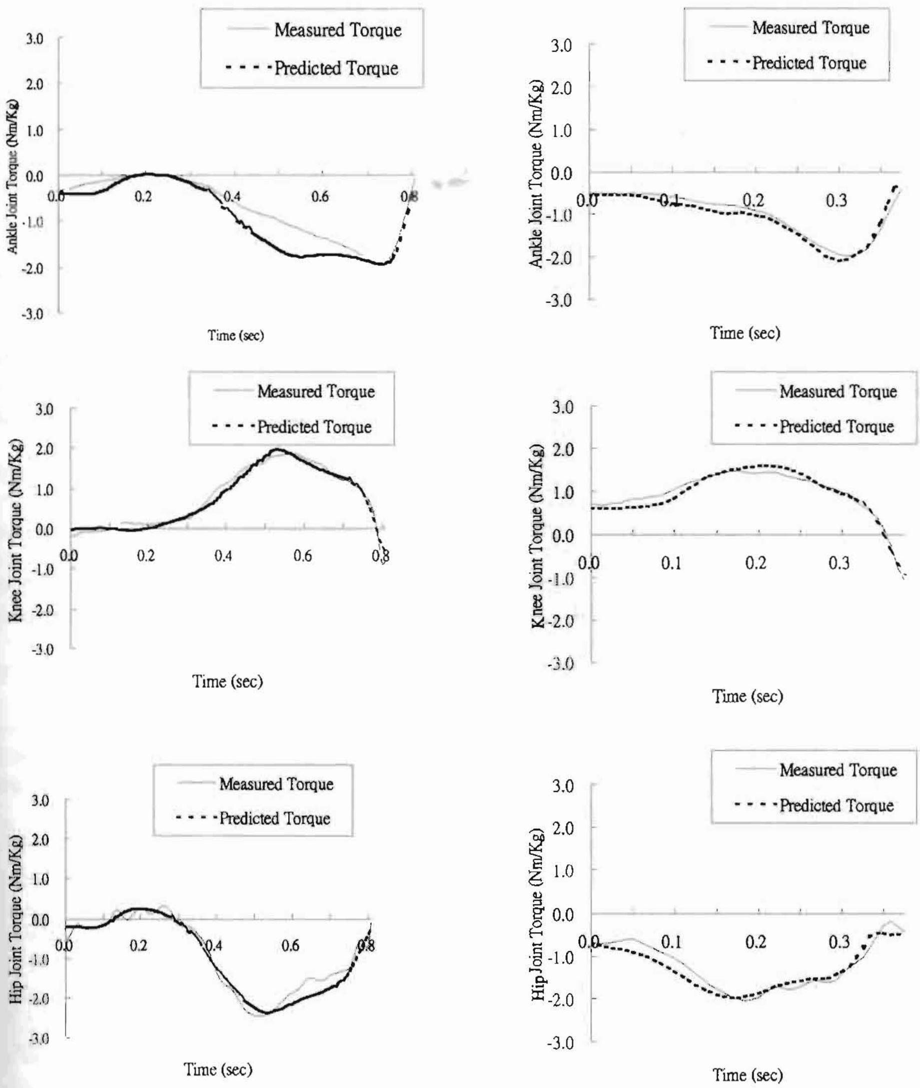

Figure 2 The measured and predicted joint torque at ankle (top), knee (middle) and hip (button) during CMJ (left) and SJ (right).

Both for CMJ and SJ, the value of RMS error for training samples was less than 0.42 and for testing samples was less than 0.47, revealing that the prediction errors of the ANN model in present study were well convergent. The Figure 2 shows that the predicted curves of joint torque fit not only the measured curves well, but they were also smoothed slightly.

DISCUSSION: In this study, the subject's body weight and height, was not included in the input variables, since the time variables of GRF, vertical displacement and speed of c.m. and power have already encompassed these properties of the subjects. In fact, the variables such as displacement and speed of c.m. and power embodied the information of the connections between the preceding and the subsequent data during the running of the model. If the variables of displacement, speed etc. were eliminated, the prediction power of the ANN model seems to be decreased accordingly based on our results of trials.

As shown in Figure 2, the ANN model not only agrees well with the experimental data, but it fits also the curves very well. This is also approved by the correlation coefficients, because all correlation coefficients between predicted and measured torque were greater than 0.95. In addition, though the fitting quality of the curves, it seems confirmed that the ANN possesses the abilities of filtering and admitting noise (Schalkaff, 1997).
Based on the results, it could be summarized that the ANN model developed in this study is feasible in the assessment of joint torque using solely the GRF parameters without inverse dynamics calculation for CMJ and SJ.

CONCLUSION: A back propagation ANN was developed by trial-and-error optimization technique to predict the lower limb's joint torque using solely GRF during CMJ and SJ. The results indicate that the ANN model developed in this study is feasible in the assessment of joint torque without inverse dynamics calculation for CMJ and SJ. After improvement of the ANN model with large number of subjects, it is believed that this kind of ANN model might be used together with the force platform software to evaluate in depth the athletes' joints torque in lower limbs beside strength and power during vertical jumping.

REFERENCES:

Bosco, C. (1999). *Strength Assessment with the Bosco's Test*. Rome: Italian Society of Sport Sicence.
Luh, J.J., Chang, G.C., Cheng, C.K., Lai, J.S. & Kuo, e-S. (1999). Isokinetic elbow joint torque estimation from surface EMG and joint kinematic data: using an artificial neural network model. *J Electromyography & Kinesiology 9*, 173-183.
Robertson DGE, et al. (2004). *Research Methods in Biomechanics (pp.103-123)*. Champaign, IL: Human Kinetics.
Schalkaff RJ. (1997). *Artificial Neural Network*, New York: McGraw-Hill Companies Inc.
Zernicke, R.F. (1996). Biomechanical Insights into Neural Control of Movement. In L.B. Rowell & J.T. Shepherd (Eds.) *Handbook of Pysiology: Sec. 12: Exercise: Regulation and integration of multiple systems* (pp.293-330). Oxford, NY: Oxford University Press.