POSTURAL CONTROL STRATEGIES IN PEOPLE WITH AND WITHOUT PERIPHERAL NEUROPATHY - A NEURAL NETWORK APPROACH

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INTRODUCTION

Postural control strategies (PCS) during perturbed, upright stance depend on the integration of multiple sensory feedbacks by the central nervous system. People with peripheral neuropathy (PN) have decreased mechanoreception in the foot. This sensory change may lead to modified PCS when their balance is disturbed. The goal of this study was to use an Artificial Neural Network (ANN) model to quantify the motor-sensory relationship during a dynamic, human postural control task in elderly people with PN and without PN (NPN).

METHODS

Five PN (73.6±3.2 yrs) and seven NPN (80.1±8.5 yrs) elderly subjects participated in the postural perturbation experiment – maintaining an upright balance when the supporting base is suddenly rotated toes-up-down around the ankle joints (maximum rotation of 12^o in each direction, maximum speed of 50^o/s). All subjects signed a consent form approved by the IRB at the University of Vermont.

Following measurements were done: the electromyography (EMG) of the tibialis anterior (TA) and gastrocnemius (GAS) muscles of both legs, the distance between the eyes' center to a gaze target in front of the subjects; the head linear and angular accelerations; the ankle rotation; and the normal and shear forces under the feet. All signals were properly low-pass filtered, synchronized, and sampled by a data acquisition system (Bioengineering Technology Systems). Trials 11-25 were collected for each subject, five seconds each trial.

A two layer ANN model was constructed with seven inputs (head angular and linear accelerations (P_1 and P_2), eye-target distance (P_3), ankle rotation (P_4), ankle velocity (P_5), normal and shear forces under the feet (P_6 and P_7)), two outputs (i.e., EMG envelopes of TA (y_1) and GAS (y_2) muscles).

The ANN model was trained based on the Back-Propagation algorithm. For every trial, the ANN model was trained 120 times, 10,000 epochs each, and a goal error of 0.001. For each training, a set of weights was determined and was used to calculate a set of 14 Q values (one for each of the 14 input-output pairs) to estimate the contribution of each sensory stimulus to each leg muscle activity [1]:

$$Q_{ki} = \frac{cp_{ki}^1 \int_T P_i \cdot y_k dt}{4\int_T y_k{}^2 dt} \times 100\% \qquad (k=1,2,\ i=1\text{-}7) \qquad (1)$$

$$cp_{ki}^1 = \sum_j W_{jk}\omega_{ij} \qquad (k=1,2,\ i=1\text{-}7,\ j=1\text{-}50) \qquad (2)$$

where Q_{ki} is the Q value between the i^{th} input variable (P_i) and the k^{th} output variable (y_k), ω_{ij} and W_{jk} the first and second layer weights, respectively, and T the total time duration of the platform movement. The group means of each Q value were compared with a two-sample, unequal variance t-test.

RESULTS

The time trajectories of the input and output variables were consistent, and there were no significant group differences in the peak-to-peak values except for the normal force, shear force and EMG of the GAS muscle (significantly smaller in PN group, $p < 0.009$).

For the Q values, there were marginally significant group differences ($p<0.10$) for each muscle (Table 1). For TA muscle, the PN group had a higher Q value for ankle angle and head linear acceleration than the NPN group ($p<0.06$). For GAS muscle, the PN group had a higher Q value from head angular acceleration than the NPN group ($p=0.075$).

Table 1. Group means and standard deviations of Q values

Outputs	Inputs	NPN	PN	P value
TA	Head ang acc	1.4 ± 1.1	1.4 ± 1.6	0.499
	Head linear acc	0.2 ± 0.1	1.3 ± 1.3	0.061
	Vision	2.4 ± 1.8	1.3 ± 1.1	0.107
	Ankle angle	1.4 ± 0.6	3.3 ± 2.1	0.057
	Ankle velocity	2.8 ± 1.4	2.7 ± 1.2	0.449
	Shear force	3.6 ± 2.9	4.3 ± 2.0	0.267
	Normal force	1.6 ± 1.4	1.0 ± 0.8	0.114
GAS	Head ang acc	0.3 ± 0.2	0.6 ± 0.3	0.075
	Head linear acc	0.6 ± 0.6	0.4 ± 0.3	0.193
	Vision	7.5 ± 11.2	3.5 ± 2.3	0.197
	Ankle angle	1.2 ± 0.6	1.7 ± 1.6	0.294
	Ankle velocity	1.6 ± 1.4	2.5 ± 1.6	0.183
	Shear force	1.7 ± 1.8	2.9 ± 3.4	0.161
	Normal force	2.0 ± 2.4	2.3 ± 1.4	0.310

DISCUSSION AND CONCLUSION

This study examined the quantitative relations between each of the seven mechanical stimuli to the visual, vestibular and somatosensory systems and each of the two leg muscle activities during a sudden toes-up-down rotation of the supporting base among elderly people with and without severe loss of cutaneous mechanoreception in the feet. There were two main findings. First, people with PN have increased dependence on vestibular system or ankle joint receptors. Second, the primary sensory contribution to both muscle activities remains from the somatosensory system in the PN group. It is possible that these subjects still maintain the use of this afferent information from the ankle joint, but with increased assistances from other sensory systems.

These findings are supported by the notion that when portions of the somatosensory receptors are eliminated, there are increased contributions from other sensory systems [2-4]. This study demonstrates the potential of the ANN model in quantitatively studying motor-sensory relationship in human postural control.

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