CHANGES IN EMG ACTIVITIES DURING TIME-COURSE OF ORTHOTIC GAIT TRAINING

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INTRODUCTION

It has been well established that locomotor-like electromyographic (EMG) activity observed in the paralyzed lower-limb muscles of spinal cord injured (SCI) persons is induced by the effective partial body weight support concomitant with the subject standing on a moving treadmill. Since the gain of spinal neural circuits generating the locomotor-like EMG activity is known to involve some use-dependence, it was suggested that treadmill training in SCI persons improves the gain of these neural circuits (Wickelgren 1998). Our previous studies (Kojima et al., 1998, 1999) suggested that if kinematic and/or kinetic patterns are sufficient to evoke the sensory inputs needed to enhance the output of the spinal neural circuits, then locomotor-like EMG activities could be induced during orthotic gait exercises. Hence, we hypothesized that the locomotor-like EMG activity observed during orthotic gait exercises first appears when the SCI patient becomes more adept during the course of their orthotic gait training. To test this hypothesis, the present study was designed to clarify the relationship between the changes in kinematic and/or kinetic patterns of the orthotic gait and the accompanying EMG activities in lower-limb muscles during the course of orthotic gait training.

METHODS

A male subject with complete paraplegia (age 22; level of lesion Th12; post-traumatic period 10 months) was trained to walk with a long brace orthosis, also known as a 'weight bearing control (WBC) orthosis', for 12 weeks, twice a week for 1-2 hours. In this orthosis, the knee joint was fixed with a bail lock during walking. The subject wearing the orthosis was connected through a set of springs to an overhead crane device, which slid along a railing parallel to a walkway of about 10 m in length, and instructed to walk along that walkway. The vertical (Fz), forward-backward (Fy), and side-to-side (Fx) components of the ground reaction force were measured using a force platform. Surface EMG activity was bilaterally measured in the soleus (Sol), the medial gastrocnemius (MG), the tibialis anterior (TA), the rectus femoris (RF), and the biceps femoris (BF). All EMG signals were amplified and transmitted telemetrically. Reflective anatomical landmarks were placed on the skin at locations corresponding with the first metatarsophalangeal joint, heel, lateral malleolus, knee joint, greater trochanter, wrist, elbow, shoulder, center of the neck, and top of the head. Additionally, two landmarks were placed on the stick. Joint positions of the lower-limb in the sagittal plane and data obtained from the force platform and telemeter were collected at 60 Hz and 600 Hz respectively using a motion analysis system (VICON 370). A total of 6 strides for each week (1, 2, 3, 4, 10, and 12 weeks after the start of the training) were analyzed. Results with p < 0.01 were accepted as statistically significant.
RESULTS

On the first day, the subject was able to walk independently at 12 m/min with a step length of 0.35 m with the orthosis. No EMG activities, however, accompanied this independent walking activity (Fig. 1A). At 3 weeks after the start of the training, the orthotic gait pattern was drastically improved. The subject achieved a higher walking speed (16 m/min) by increasing his step length (0.45 m). This improvement in the orthotic gait pattern was associated with a larger displacement and greater angular velocity in the direction of hip extension (Fig. 1B). Accompanying these improvements in kinematics, the subject experienced larger impact peaks for the vertical component of the ground reaction force (Fig. 1B). Furthermore, a soleus EMG burst was consistently observed during hip extension at the middle of the stance phase (Fig. 1B). No other modulated EMG activities were observed during the step cycle.

At 12 weeks after the start of the training, the subject was able to walk independently at 21 m/min with a step length of 0.47 m. Also at this time, a more clearly modulated soleus EMG activity was observed. The relationship between soleus mean EMG activities during the stance phase in each step cycle and the kinematics and kinetics variables in that cycle was examined. The soleus mean EMG activity correlated significantly with the hip extension movement as well as with the vertical component of the ground reaction force. The correlation coefficients for the hip extension were 0.68 for the angular displacement and 0.68 for the velocity (Fig. 2A, B), and for the vertical component of the ground reaction force the correlation coefficients were 0.71 and 0.74 for the 1st and 2nd impact peaks, respectively. (Fig. 2E, F) But no such significant correlation was observed in the ankle dorsiflexion movement (Fig. 2C, D).

![Fig. 1 Rectified EMG, kinematics, and the vertical component of the ground reaction force (GRF) for the lower-limbs of a during spinal cord injured (SCI) subject during an orthotic gait exercise. A: 1 week after the start of the training. B: 3 weeks after the start of the training. C: 12 weeks after the start of the training. The muscles observed were the soleus (Sol), the medial gastrocnemius (MG), and the tibialis anterior (TA). The stance phase is the duration from touchdown (TD) to takeoff (TO).]

DISCUSSION

The results indicated that the soleus EMG activities observed during the course of orthotic gait training were closely related to an improvement of the hip extension movement as well as to the limb load during the stance phase. Several possible interpretations of the appearance of the locomotor-like EMG activity are: 1.) Some amount of sensory input concerning hip extension movement and limb load experienced during the course of the orthotic gait training was sufficient to enhance the output of the spinal neural circuit, or 2.) This phenomenon can be achieved without any changes in the spinal neural circuit itself. Taken together with recent findings on the locomotor capacity of SCI individuals, it is conceivable that...
the alterations in spinal neural circuit activity occurred in response to the orthotic gait training, and resulted from changes in the efficacy of existing neural connections.

Fig. 2 Relationship between the mean soleus EMG activity and the angular displacement during hip extension (A), the angular velocity during hip extension (B), the angular displacement during ankle dorsiflexion (C), the angular velocity during ankle dorsiflexion (D), 1st impact peaks for the vertical component of the ground reaction force (E), and 2nd impact peaks for the vertical component of the ground reaction force (F). There were significant relationships in A, B, E, and F.

REFERENCES
