The Effect of Stimulated Trunk Extension on the Upright Body Weight Distribution While Standing with Functional Neuromuscular Stimulation

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Abstract

The recipients of the CWRU/VA standing neuroprosthesis have demonstrated the ability to stand with less than 10 percent of their body weight on the arms. In this study, we investigated the role of trunk extension generated by the stimulated erector spinae muscles in the performance of this system. In two subjects with SCI, the erector spinae muscles were bilaterally deactivated while upright to measure the change in body weight distribution. The body weight distribution was measured using a pair of forceplates and a pair of instrumented parallel bars. Deactivation of the erector spinae muscles resulted in arm support forces increasing from 5% to 29% in one subject and from 11% to 49% in the other. These results indicate that the users of standing neuroprosthesis which activate the erector spinae muscles are able to support a larger portion of their body weight on their legs, thus increasing their ability to remove a hand from the support device to manipulate objects in their environment.

Introduction/Background

This study was designed to determine the role of the erector spinae muscles in the performance of an implanted neuroprosthesis utilizing functional neuromuscular stimulation (FNS) for standing after spinal cord injury (SCI). The CWRU/VA standing neuroprosthesis consists of an eight-channel implanted receiver-stimulator, six epimysial electrodes activating bilateral vastus lateralis, gluteus maximus and semimembransosus, and two intramuscular electrodes activating bilateral erector spinae (ESPINE). Recipients of this system can typically stand with less than 10% body weight (BW) on their arms, enabling them to remove a hand from the support device to manipulate objects in their environment. This investigation determined the contribution of the lumbar erector spinae to this distribution of BW between the legs and arms while standing with the assistance of a support device. We hypothesized that FNS standing with inactive erector spinae muscles would result in more anterior trunk tilt, increased arm support forces, and thus an increased reliance on the support device.

Methods

The CWRU/VA standing neuroprosthesis is implanted in a single surgical procedure lasting approximately nine hours [1]. During this procedure, two intramuscular electrodes are implanted near the T12 or L1 nerve roots to bilaterally activate the erector spinae muscles (Iliocostalis Lumborum, Longissimus Thoracis and Spinalis Thoracis). Surgically implanted intramuscular electrodes [2] are used because the segmental innervation of the erector spinae muscles make them unsuitable for activation using epimysial electrodes.

Following a one-week post-operative recovery period and a six-week period of restricted activity, each recipient of the standing neuroprosthesis commences an eight-week period of daily exercise to strengthen the muscles prior to standing. Training in the techniques required for wheelchair transfers and standing with the system continues under the guidance of a therapist until proficiency is demonstrated.

To date, a total of ten persons with SCI have received the CWRU/VA standing neuroprosthesis. Seven have progressed through the standing phase of the rehabilitation protocol, one recently started standing training, and two are exercising in preparation for standing. Two of the seven who have completed standing training volunteered for this study. A summary of these two volunteers appears in Table 1.

Table 1. Subject Characteristics

Subject	Sex	Implant Date	Age at Implant (months post-injury)	Injury Level (ASIA)	Height Mass
# 1	F	11/12/99	28 (20)	C-7 (B)	168 cm 56.8 Kg
# 2	M	12/3/99	47 (15)	T-6 (A)	173 cm 86.4 Kg

In these two volunteers, the erector spinae muscles were bilaterally deactivated while upright with the system to measure the change in BW distribution between the legs and arms. During the standing experiments, each muscle was stimulated using a biphasic, charge-balanced, asymmetric, cathodic current pulse train at 20Hz and an amplitude of 20mA. The pulse duration (PD) of each electrode was fixed at either 200uS (the stimulator maximum) or the saturation value (no subsequent increase in muscle force with increasing PD).

While upright, the forces on the legs were measured using a pair of forceplates (AMTI Corporation, Watertown, Mass.), and arm support forces were measured with a set of strain-gage instrumented parallel bars. The bilateral deactivation of the erector spinae was simultaneous, and occurred four times while upright to ensure repeatability of the results. Two trials were performed, and the arm support forces were averaged over the eight 'on/off' cycles. All other muscle stimulation parameters remained constant while the erector spinae were deactivated. A pre-fabricated ankle-foot orthosis was used to prevent rotational and inversion/eversion injuries at the ankle. A single-subject repeated measures design was employed and the subjects acted as their own controls by standing, with the neuroprosthesis, with and without activation of the paraspinal muscles. An example of the arm and leg support forces during one trial appear in Figure 1.

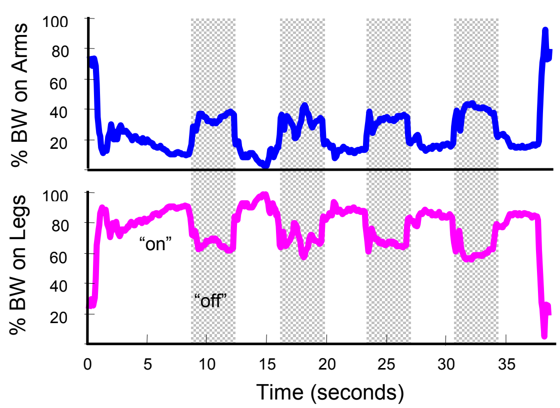


Figure 1. Arm and leg support forces during erector spinae deactivation while upright with FNS. Data normalized to BW. Data are from subject #2.

Results

Following deactivation of the erector spinae muscles while upright, both volunteers consistently exhibited increased BW support on their arms. When the erector spinae muscles were deactivated, arm support forces increased from 11% to 49% BW in one volunteer and from 5% to 29% BW in the other (Figure 2). The increase in arm support forces was accompanied by a simultaneous increase in the hip flexion angle (Figure 3).

Following reactivation of the erector spinae muscles, arm support forces and hip flexion angle both returned to their normally lower values (Figure 1).

Both of these subjects, during normal operation of the CWRU/VA standing neuroprosthesis, were able to remove either hand from the support device. Whereas, when the erector spinae muscles were deactivated, neither felt that confident about removing a hand from the support device.

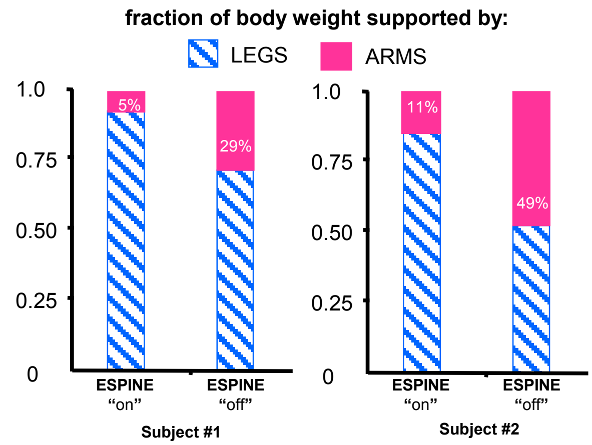
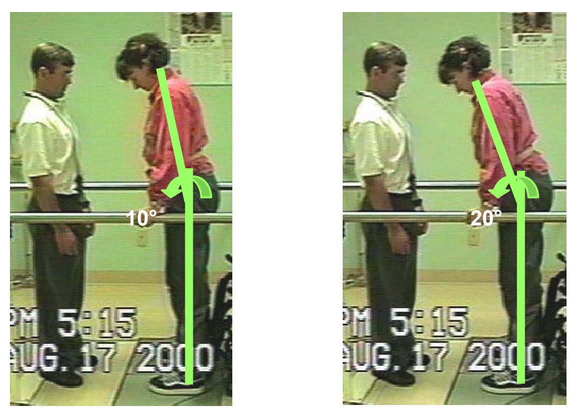


Figure 2. BW distribution between arms and legs following deactivation of the erector spinae muscles



ESPINE "on"

ESPINE "off"

Figure 3. Posture of subject #1 while upright with erector spinae muscles active (L) and inactive (R).

Discussion/Conclusions

The erector spinae muscles appear to play a vital role in performance of the CWRU/VA standing neuroprosthesis. These results indicate that these muscles can facilitate an upright posture and augment the hip extensors to ultimately reduce the BW supported by the arms while upright. As demonstrated in both subjects, deactivation of the erector spinae muscles resulted in a 4 to 5-fold increase in arm support forces over the baseline.

From these results, it is apparent that users of standing neuroprostheses that include the erector spinae are able to support a larger portion of BW on their legs, thus increasing their ability to release a hand from a walker or other assistive device to manipulate objects or perform other functional tasks while upright.

Possible reasons for these results include the ability of the stimulated erector spinae muscles to produce adequate trunk extension to align the trunk with the hips in the sagittal plane. In addition, since the bulk of the erector spinae muscles originate on the sacrum, their activation could act to fix the position of the pelvis, giving the hip extensors like semimembranosus and gluteus maximus a better anchor. The result is a more effective hip extensor, and higher hip extension moments.

Future studies will include more subjects in similar experiments to validate these results. In addition, isometric testing of the trunk extension moments created by stimulated erector spinae muscles is currently underway. It would be interesting to correlate the amount of trunk extension moment generated by stimulated erector spinae muscle to a BW distribution while upright with FNS.

From these data, it appears that the arm support threshold for removing a hand from the support device is somewhere between 11% and 29% BW. While subject #2 could remove a hand from the support device at 11% BW, subject #1 could not remove a hand at 29% BW. This finding should be further studied in order to determine if there is a level of arm support, above which, hand removal for object manipulation cannot be performed.

This study demonstrated the importance of the erector spinae muscles in facilitating an upright posture and their potential for a producing a more functional FNS standing system.

References

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Acknowledgements: This work was funded by the FDA Office of Orphan Product Development, The Rehabilitation, Research and Development Service of the Department of Veterans Affairs, and the National Institutes of Health.