Optimization of Lower Extremity Kinetics during Transfers Using a Wearable, Portable Robotic Lower Extremity Orthosis: A Case Study*

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Abstract. The ability to transfer from sitting to standing (STS) is central to independent mobility and presents a significant, unique challenge to individuals post-stroke with residual unilateral lower-extremity weakness. We examined the effect of a novel, wearable robotic lower extremity orthosis on STS transfer kinetics, including paretic limb work, in a single post-stroke individual. The device appears to improve force allocation between paretic and non-paretic limbs during STS transfers, resulting in an optimal state of paretic limb engagement at a specific level of mechanical assistance from the device.

1 Introduction

Transfer from sitting to standing is central to independent movement and mechanically one of the most demanding motion tasks of everyday living [1]. Considering the movement patters of stroke survivors, approximately 40% demonstrate moderate impairment and 15 to 30% severe disability with functional tasks [2]. Furthermore, these individuals routinely demonstrate significant kinematic differences between paretic and non-paretic limbs during transfers [3].

Conventional neurorehabilitation seeks to correct these differences and improve transfer ability and stability. Unfortunately, there is a lack of technology able to provide dosed, progressive assistance (aside from tethered bodyweight-support devices) or capture objective, real-time force output and paretic limb work data away from comprehensive motion analysis labs.

Recently, a novel wearable robotic lower extremity orthosis designed to augment concentric and eccentric knee extension has been developed to meet this need – the Tibion Bionic Leg (TBL) [4]. Recent studies have demonstrated

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improvements in balance, gait and functional performance following therapy with the device [5][6], however no prior work has examined the biomechanical effects of the device that may contribute to clinical outcomes.

We studied the effects of the TBL on paretic (P) and non-paretic (NP) limb force allocation and paretic limb work in sit-to-stand (STS) transfers. We hypothesized that via use of the TBL it would be possible to optimize these parameters in hemiparetic individuals during STS training.

2 Methods

2.1 Subject

A single male subject, 85 years old and 160 lbs was evaluated, status post a single parietal lobe ischemic stroke 7 years prior. The subject's residual impairment was characterized as Moderate by his Fugl-Meyer (90), Modified Rankin (3), and Berg Balance (45) scores; his Five Times Sit to Stand was 11.2 seconds. To minimize learning from prior device experience, the subject was naïve to the TBL prior to enrollment.

2.2 Tibion Bionic Leg (TBL)

The TBL is a wearable, portable, battery-powered robotic limb orthosis developed as an adjunctive tool for lower extremity physical therapy. Sensors under the patient's foot and within the device itself determine the type of motion being performed. The device requires intentional directional movement from the patient before providing assistive force to knee extension during transfer, stair ascent, stance, and gait; during flexion in stand-to-sit transfers and stair descent, the device provides measured resistance to decrease speed. Three settings may be adjusted to tailor the assistance and resistance provided by the device based upon the patient's bodyweight (BW) and degree of impairment: *threshold* (lower force limit patient must exceed before actuated assistance is provided), *assistance* (percent of BW that will be supplied as assistance), and *resistance* (amount of resistance provided during flexion) [4].

2.3 Intervention

Assessment began with three STS trials each of the baseline (no device, no coaching) and therapist-coached states. The TBL was then placed on the subject and a short orientation (20 overground steps) provided by the therapist. STS trials with the TBL were then conducted without therapist coaching, with three trials for each assistance setting (30 to 80% BW, in steps of 10%) to minimize learning effect; the device threshold setting was kept at a minimum of 20% of BW for all test conditions. Testing concluded with three trials of the post-TBL use state (no coaching), for a minimum total of 27 STS data collection trials. Comprehensive kinetic and kinematic motion analysis data were collected using two AMTI (Model OR6-6-2000) force plates, the Vicon Nexus camera system, and the Visual 3D software package; additional motion and force data were collected in real-time from a wireless data connection with the TBL.

2.4 Data Analysis

Kinetic data from the force plates, Vicon system, and TBL were used to compute the limb force output values (mean, max) and paretic limb work. Total limb force output for an STS trial was computed as an area under the curve (AUC) using the trapezoidal rule; these values were time-normalized against a computed ideal total. Weight and torque contributions of the TBL were removed from the paretic limb-TBL system calculations. A two-tailed Student's t-test was used to determine statistical significance (α=0.05) when comparing mean results.

3 Results

Without the TBL and coaching, the subject demonstrated significant differences in paretic (P) and non-paretic (NP) mean (288±16 vs. 397±14N, p<0.005) and maximum (383±18 vs. 522±29N, p<0.005) force allocation; with coaching this difference was maintained (Mean: 309±8 vs. 379±9N, p<0.005; Max: 397±30 vs. 504±29, p<0.005). With the TBL and different assistance settings, P and NP force was optimized between 30 (Mean: 339±11 vs. 380±8N, p<0.05; Max: 534±87 vs. 525±27N, p=0.87) and 40% (Mean: 310±60 vs. 332±70N, p=0.71; Max: 468±67 vs. 478±6, p=0.81) BW, and diverged to pre-TBL levels with increased assistance settings. Compared to the ideal total force output, P and NP values without (67±7 vs. 124±7% Ideal AUC, p<0.005) and with (79±3 vs. 113±5% AUC, p<0.005) coaching were significantly different; with the TBL, between 30 (97±9 v. 112±3% AUC, p=0.05) and 40% (97±8 vs. 108±3%, AUC, p=0.09) BW optimization was achieved, with divergence with higher assistance settings. Using the TBL, paretic limb work was greatest between 30 (13165±1128 ft-lb) and 40% (12904±5159 ft-lb) BW with lower values observed with higher TBL assistance.

4 Discussion

In this post-stroke individual we found that lower extremity force allocation and paretic limb work could be optimized through use of the TBL during sit-to-stand transfers by adjusting the mechanical assistance provided by the device. However, with increasing assistance settings beyond the ideal the patient reallocated force and work to the non-paretic limb towards values near the baseline state. Coaching from a therapist without use of the TBL did little to improve force allocation difference observed in the baseline state.

5 Conclusion

These results suggest that the use of the TBL may allow hemiparetic individuals to improve limb force allocation and paretic limb engagement during post-stroke rehabilitative therapy. When used as part of a neurorehabilitative program, the mechanics of the TBL may contribute to improved patterning of repetitive movements, possibly influencing clinical outcomes.

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