Soft robotic exosuits for targeted gait rehabilitation after stroke: A case study

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decrease hyperreflexia. Cortical and biceps EMG electrodes were implanted in adult rats, and baseline testing was done a week before SCI. A moderate C4 contusion (200 kdyne) was performed, and thin and softening electrode arrays were inserted over C5-C6. Beginning 11 days after SCI, we tested the effects of repetitive paired stimulation over 10 days. The protocol uses intermittent bursts to deliver 3000 stimuli over 30 minutes every day for 10 days. After this protocol, rats with SCI had large (>150%) augmentation of both cortical and spinal motor evoked potentials (MEPs) that decreased over 2 hours to 50% increase. The magnitude and the duration of the effects were similar in rats with and without SCI, indicating that spared circuits mediate pairing effects. In the group of rats with repetitive stimulation, but not an injury only control group, MEPs increased more than 2-fold over the 10-day stimulation period. The difference between groups was maintained weeks after SCI, indicating a durable change in physiology. In both groups, SCI diminished the rate-dependent decrease in the H-reflex, consistent with hyperreflexia. After 10 days of paired stimulation, rats with stimulation had much less hyperreflexia than injury-only controls. Thus, paired stimulation produces stronger cortical and spinal MEPs, decreased hyperreflexia and the circuits spared after SCI were sufficient to enable long-term plasticity.

Keywords. electrical stimulation, spinal cord injury, paired stimulation, H-reflex, spasticity, neuromodulation

T50: Transcranial Direct Current Stimulation Over Lesioned Motor Cortices Reduces the Expression of the Flexion Synergy and Nonlinear Brain-Muscle Connectivity in Hemiparetic Stroke

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A hallmark impairment post-stroke is a loss of independent joint control in the paretic arm resulting in abnormal co-activation of shoulder abductors and arm/hand/finger flexors, clinically known as the flexion synergy. Evidence from previous studies indicates that the flexion synergy is likely caused by an increased abnormal reliance on the non-lesioned cortico-reticulospinal tracts (CRST) after a stroke-induced loss of direct corticofugal projections. Our recent work demonstrated that the expression of the flexion synergy is associated with enhanced nonlinear connectivity between the brain and muscles from the contralesional hemisphere. This is very likely because nonlinear processing of cortical input is cumulatively enhanced when the motor command passes through multiple synaptic connections of the CRST. Recent studies and meta-analysis indicate that non-invasive brain stimulation such as transcranial direct current stimulation (tDCS) can improve the motor function of paretic arm post stroke. However, the neural mechanism underlying its effects is still unknown. We hypothesize that anodal tDCS over lesioned motor cortices improve the arm function via facilitation of residual corticospinal projections and therefore reducing reliance on the CRST. If so, the anodal tDCS should reduce the expression of flexion synergy and nonlinear brain-muscle connectivity (BMC). In this preliminary study, we measured the flexion synergy elbow torques, brain signal (EEG) and muscle activity (EMG) in 3 chronic hemiparetic stroke participants when lifting their paretic arm with 30% of their maximum voluntary shoulder abduction torque before and after 20 min anodal tDCS stimulation over the motor region in the lesioned hemisphere (current density: 0.04 mA/cm^2). The nonlinear connectivity between EEG and EMG (i.e., nonlinear BMC) was estimated by using a novel signal processing method that is a nonlinear extension of corticomuscular coherence method based on high-order spectra. We found that the flexion synergy elbow torque and nonlinear BMC decreased after the tDCS. This result supports our hypothesis and indicates that tDCS has the potential to be combined with physiotherapeutic interventions that aim at reducing the maladaptive usage of the CRST and associated motor impairments post hemiparetic stroke.

T51: Chronic Stroke Hemispheric Dominance and Task Specific fMRI Laterality of Cortical Motor Activation

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Chronic stroke fMRI studies suggest that greater lateralized activity in the ipsilesional hemisphere during movement of the impaired upper-limb is associated with better motor outcomes, whereas bilateral activation is associated with poorer motor outcomes. These studies help inform therapeutic research interventions that aim to promote motor recovery by increasing the activity of the ipsilesional hemisphere and decreasing the activity of the contralesional hemisphere through methods of non-invasive brain stimulation and forced practice of the impaired upper-limb. But, recovery following these interventions is variable, suggesting that targeting hemispheric laterality may not be the most efficacious approach. Factors that may influence laterality index and its usefulness in predicting motor disability are hand dominance relative to the impaired upper-limb and the task performed during fMRI. Our objective was to explore whether laterality of cortical motor activation can, in part, be explained by hemispheric dominance and task specificity, similar to previous able-bodied studies. Twenty-eight, right handed participants with chronic hemiplegia and 22 age-matched able-bodied participants performed either whole-hand self-paced flexion-extension (non-dominant hemisphere lesion: $N = 6$; dominant hemispehre lesion: $N = 13$; able-bodied controls: $N = 12$) or whole-hand sinusoidal wave tracking (non-dominant hemisphere lesion: $N = 4$; dominant hemisphere lesion: $N = 5$; able-bodied controls: $N = 10$) of the impaired limb inside the scanner. Group fMRI analysis revealed broad activation patterns within the higher motor, motor, and parietal regions for both tasks and greater laterality during dominant hand tracking. However, overall, there is greater bilateral activation in participants with non-dominant hemisphere lesions during paretic hand self-paced flexion extension and sinusoidal wave tracking, and these results are comparable to non-dominant hand movements within the controls. These results may help explain the variance in recovery following therapies that aim to increase activity in the ipsilesional hemisphere and may offer alternative therapeutic cortical targets dependent on impaired hand dominance and task specificity.

T52: Soft Robotic Exosuits for Targeted Gait Rehabilitation After Stroke: A Case Study

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Introduction: Reduced forward propulsion and foot clearance are pervasive deficits in post-stroke gait that limit post-stroke recovery. Our team has developed a soft robotic exosuit that provides assistive torques in parallel with the paretic ankle plantarflexor and dorsiflexor muscles, showing immediate augmentation of paretic propulsion and foot clearance, a reduced energy cost of walking[1], and increased walking speed and distance[2]. We posit that these immediate benefits can be enhanced by gait training with the device and leveraged to produce gait improvements that persist beyond the use of the device. This preliminary study aimed to assess the rehabilitative effects of an exosuit-augmented gait training program on targeted clinical and biomechanical outcomes.

Methods: A 58-year old male with chronic (54 mo) left-sided hemiparesis was enrolled in this case study. Using a crossover design, we administered exosuit-augmented gait training followed by comparable gait training without the exosuit. Each intervention consisted of six sessions of training provided over a 2-week period, separated by a 7-week washout. For both interventions, a physical therapist administered progressive, task-specific, and high-intensity gait training directed at increasing walking speed. To assess the effect on clinical outcomes, the 10-Meter Walk Test and 6-Minute Walk Test were performed before and after each intervention. To assess the effect on biomechanical impairments, evaluations were conducted before and after each intervention on an instrumented treadmill at matched walking speeds. All evaluations were conducted without the exosuit. Examination of pre-to-post changes was based on 95% confidence intervals and paired *t*-tests, with alpha level at 0.05.

Results: As hypothesized, exosuit-augmented gait training produced meaningful changes[3] in fast walking speed (pre-post Δ: +0.12 m/s) and walking distance (pre-post Δ: +86 m). In comparison, training without the exosuit resulted in modest increases in fast walking speed (pre-post Δ: +0.04 m/s) and walking distance (pre-post Δ: +37 m). Similarly, exosuit-augmented gait training resulted in increased paretic ankle angle at push-off (+58.78%), stride length (+6.70%), paretic ankle plantarflexion moment (+8.33%), and paretic propulsion (+10.52%) (p's < 0.05). In contrast, gait training without the exosuit failed to demonstrate changes in ankle angle at push-off, stride length, and ankle plantarflexion moment ($p > 0.05$). Instead, there was a reduction in forward propulsion (-9.18%) ($p < 0.05$). Taken together, these results demonstrate that exosuit-augmented gait training uniquely retrains a propulsion-based walking strategy not observed after gait training without an exosuit.

Conclusion: This case study provides early evidence that targeted gait training with a soft robotic exosuit may deliver improved walking outcomes compared to gait training without an exosuit. The results from this case study encourage further examination in larger samples.

T53: Understanding Enablers and Barriers to Using Technology with People with Traumatic Brain Injury

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Research has shown that people with neurological disorders experience continued improvement in speech, language, and cognitive skills with ongoing rehabilitation. Despite this, barriers such as insurance coverage and proximity to clinics can hinder a patient's ability to access the therapy required for optimal functional recovery. To offset this lack of sufficient therapy, the use of home-based technology in rehabilitation has become a growing area of research. The use of technology presents its own challenges, however, with engagement tending to be lower among the elderly and those that live in rural areas. This study retrospectively analyzed the data for patients with traumatic brain injury (TBI) that used Constant Therapy (CT), a cloud-based rehabilitation program that delivers standard speech and language therapy exercises via tablet, to determine if usage patterns differed by patient demographic characteristics. User demographics included age, gender, time post-onset, and urban vs. rural geographic location. Activity metrics examined were 1) the total number of completed therapy sessions and 2) the average number of active days per week, both during the first 20 weeks of CT use. The effect of demographic covariates on therapeutic activity was assessed using ANOVA and linear regression. 646 patients with TBI and a language and/or cognitive deficit were included in the analysis, with a mean age of 48.9 years ($\pm$18.1), 41.5% female, 8% living in a rural location, and 42.3% having acute condition ($\leq$6 months post-onset). The average patient completed 35.4 therapeutic sessions and engaged with the platform 3.1 days per week. ANOVA results suggest a statistically significant effect of gender ($F(1,644)=6.33$, $p<0.05$) and acute condition ($F(1,644)=5.28$, $p<0.05$) on the total number of sessions completed, and no statistically significant effect of any demographic characteristic on the average number of active days per week. After controlling for all model covariates, patients with chronic TBI completed 7.96 more sessions than patients with acute condition ($p<0.05$) and male patients completed 8.44 more sessions than female ($p<0.01$). Results from the linear regression confirmed no statistically significant impact of age, gender, geographic location or acute status on the average number of days per week a patient engaged with the digital platform. Although the average TBI patient in our sample was young and lived in an urban setting, patients that were older or from a rural location did not differ in their use of digital therapy after accounting for gender and time post-TBI onset. Our results suggest that typical barriers to technological adoption may not impact a patient with TBI's ability to engage with home-based rehabilitation technology. However, clinical characteristics such as time post-onset suggest that chronic TBI survivors likely need and are able to access digital rehabilitation.

T54: Virtual Reality Treatment for Phantom Limb Pain

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Up to 90% of amputees experience sensations in their phantom limb, often including strong, persistent phantom limb pain (PLP). Standard treatments do not provide relief for the majority of people who experience PLP, but virtual reality (VR) has shown promise. This proof-of-concept small-scale clinical trial provides additional evidence that game-like training with low-cost immersive VR activities can reduce PLP in transtibial lower-limb amputees. Six participants attended 5-7 sessions in which they experienced a visually immersive experience without leg movements, followed by 10-12 sessions of targeted lower-limb VR treatment (custom games played with leg movements, accompanied by real-time rendering of two intact legs in a head-mounted display). A motion tracking system mounted on the intact and residual limbs controlled the movements of both virtual extremities. All participants except one experienced a significant reduction of pain immediately after each VR session, and their pre-session pain levels also decreased greatly over the course of the study. Additionally, there was preliminary evidence that the targeted lower-limb treatment may be more efficacious than the distractor treatment. The low-cost VR intervention we assessed appears to be a feasible and efficacious treatment of PLP in lower-limb amputees.