

# Clinical training and competency guidelines for using robotic devices

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**Keywords:** Robotic, Training, Competency

## Purpose/Hypothesis:

Despite the increasing popularity of robotic devices in rehabilitation centers worldwide, few of the device manufacturers have provided rigorous guidelines on how to properly train and evaluate therapists on the safe and effective use of their machines. Developing comprehensive training and competency evaluation guidelines will help ensure that these devices are used properly, which will lead to more effective interventions and reduce the likelihood of injury. The goal of this project was to create generalized guidelines and competency evaluation tools for the safe and effective use of rehabilitation robotic devices.

Number of Subjects: Six device manufactures and fourteen clinicians (9 Physical Therapist, 3 Occupational Therapist, 2 MDs) participated in this project.

## Materials/Methods:

Guidelines were developed through a consortium of therapist, engineers and device manufactures and clinical organizations. Generalized procedures for each of these components were first developed by NRH, and then circulated first through a group of elite device manufactures to review the training options and then through a group of clinicians who specialize in the area of robotics to focus primarily on the competency assessment piece. A series of telephone/web conferencing calls were held to analyze and revise the guidelines.

## Results:

The end product is a tool that can be used by robotic device manufacturers and/or end users to help them identify what type of documentation and training should be provided with their device. The guidelines include: 1) detailed content for the user's manual 2) clinical resource manual, 3) hands-on training process, 4) training videos 5) web based educational tools and 6) competency assessment.

The format of the document is designed as a check list. The user places a check next to all those items they feel are appropriate for the device. The document directs the user to choose the training tools that should be provided for the device and for each tool, general guidelines for content.

## Conclusion:

We believe that device manufactures and clinicians will find this document useful for two reasons: 1) Having established guidelines will help them save time and money when developing procedures for devices 2) Comprehensive, thorough training procedures will lead to proper use and consequently reduce the risk of injuries.

Support: Department of Defense Telemedicine and Advanced Technology Research Center (TATRC) Award Number: W81XWH-09-2-0131

# Combining Lokomat stepping with transcutaneous spinal cord stimulation to measure and augment locomotor recovery after SCI

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**Keywords:** H Reflex, Posterior Root Muscle Reflex (PRMR), Body Weight Supported Treadmill Stepping.

Robotic body weight supported treadmill training has been used as therapy to improve gait recovery in motor incomplete spinal cord injury (SCI) with some degree of success. We understand little, however, about the neural plasticity that this training generates to cause functional recovery. We also do not know why different patients realize different degrees of functional recovery with training and why some groups, namely motor complete SCI, don't recover gait function despite training.

Needed is a method for measuring the neural plasticity generated by gait training and a method for augmenting that training. We have turned to electrophysiological techniques to address these issues.

Previously, we used classic soleus H-reflexes recorded at specific times during the gait cycle as a measure of neural processing in the injured spinal cord and as a measure of neural plasticity over the course of robotic gait training (1). While this method was revealing, it only gave us information about one muscle.

More recently, we have adopted the technique of stimulating structures within the spinal canal rather than the peripheral nerves to generate simultaneous monosynaptic reflexes in all the lower extremity muscles. These so-called posterior root muscle reflex (PRMR) can be generated with transcutaneous spinal cord stimulation (tSCS) (2).

We are now performing tSCS to generate PRMRs in subjects in the Lokomat to study these reflexes at specific times during the gait cycle and over the course of robotic gait training. We can simultaneously measure reflex modulation at mid-stance in one leg and at mid-swing in the other and are beginning to

characterize these reflexes in the different lower extremity muscles across the spectrum of the SCI patient population.

PRMRs are elicited with single stimuli but when tonic stimulation is applied, a more complex response in the spinal neural circuitry is elicited. This was initially described using epidural stimulation (3) and it was shown that, even in complete SCI, locomotor movements can be evoked.

We are now combining tonic tSCS with Lokomat stepping to characterize the interactions between stimulation parameters like frequency and amplitude and gait training parameters like loading and gait speed. In a subject with motor incomplete SCI, we have found that increasing loading and treadmill speed increases the EMG activity in the lower extremities and that this was further augmented with tonic tSCS at sub-motor stimulation strengths (4).

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# Robotic training of proximal upper extremity stabilization during distal motor activity in persons with upper extremity hemiparesis.

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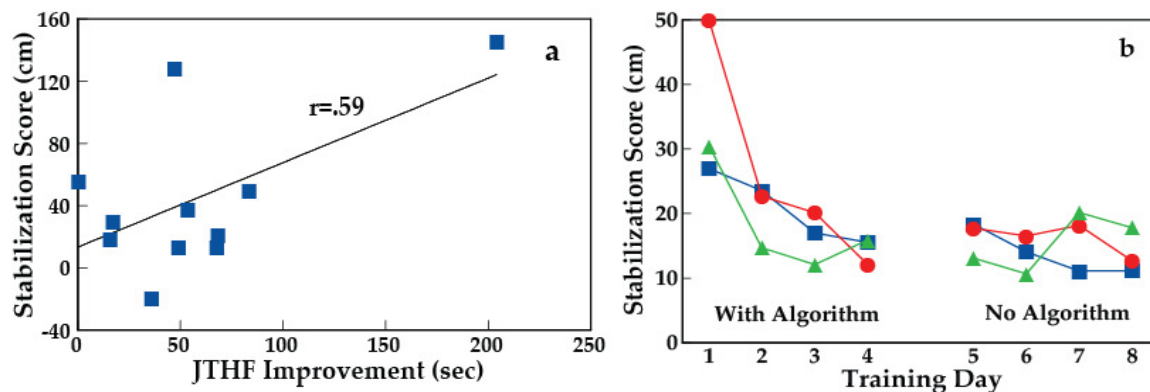
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**Keywords:** Robotics, Virtual Reality, Upper Extremity, Rehabilitation, Stroke.

One aspect of upper extremity (UE) motor function critical to normal, real-world use is the ability to stabilize the hand as it interacts with an object. Robotic training techniques studied in persons with hemiparesis due to stroke focus on the proximal segments, acting as primary movers during a reaching movement, or the hand performing a fine motor task. To date, no robotic training studies consider the ability to maintain the hand in a stable position as it interacts with a target. We will present data suggesting a correlation between improvement in the ability to stabilize proximal segments during distal effector activity and improvements in hand function. We will also discuss an algorithm designed to shape UE stabilization in persons with UE hemiparesis. **Study One:** 11 subjects, with hemiparesis, participated in eight sessions of training utilizing the NJIT-RAVR system, using the HammerTask simulation, which trains the subject to perform a reaching movement toward a peg and then perform repetitive finger extension movement to “hammer” the peg. All 11 subjects

demonstrated improvement in the ability to stabilize the hand over the peg during hammering. This improvement demonstrated a statistically significant correlation with improvement in the Jebsen Test of Hand Function (JTHF) ( $r = .59, p = .05$ ) which was stronger than correlations with reaching trajectory smoothness and peak finger extension and JTHF improvement. **Study Two:** We attempted to shape UE stabilization during HammerTask training using an algorithm that scales target size based on task performance. Three subjects with stroke performed 4 days of training, using an algorithm that reduced the yaw plane area of the target peg by ten percent after the subject successfully hammered a peg in less than 10 seconds, and increased the area after unsuccessful attempts. This was followed by four days of training without the algorithm. All three subjects made larger improvements in stabilization and Wolf Motor Function Test score during the algorithm training period compared to changes following training with no algorithm.

**Figure 1:** a) Improvements in JTHF Time and Mean decrease in stabilization score b) Daily stabilization score secondary to training with and without algorithm



# Increases in hip torque and electromyography with applied ankle load in incomplete human spinal cord injury

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**Keywords:** human, spinal cord injury, rehabilitation, sensory processing.

Stretch and load related sensory information has been shown to be important for modulating the timing and magnitude of lower extremity muscle activity during walking in animal models of spinal cord injury (SCI). It is not well known if augmented sensory information can improve leg strength and coordination in humans post SCI.

The aim of this study was to examine the affect of ankle loading on hip muscle activity during bilateral hip oscillations. We proposed that, for SCI, load application would result in increased hip torque and electromyography (EMG) as compared to no load.

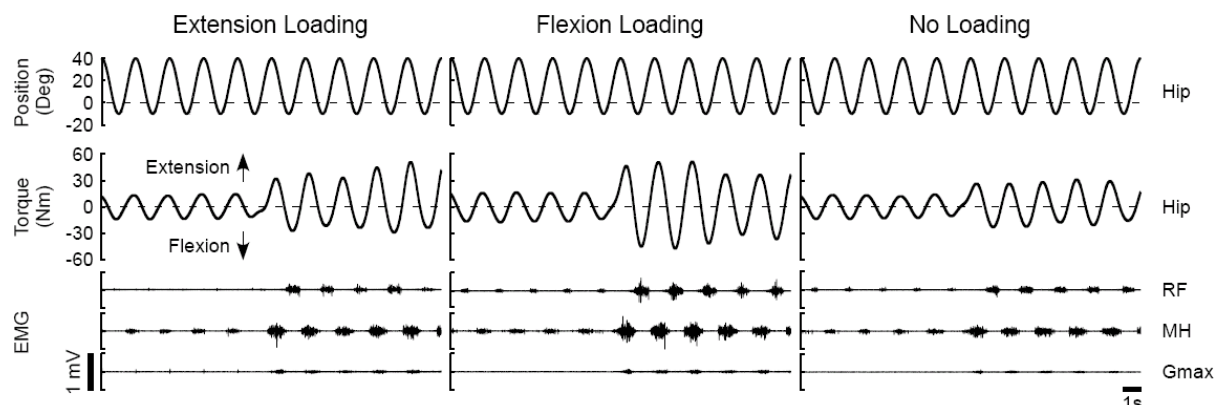
Influence of additional joints and sensory systems (e.g. vestibular) were minimized by positioning the subject recumbent and localizing movement to the hip and ankle joints. Hip oscillations and ankle load were applied via a custom lower limb robot consisting of bilateral servomotor drive systems (Kollmorgen, Northhampton, MA) and pneumatic rotary actuators (Kuroda, Kanagawa, Japan), respectively. Thirty consecutive hip oscillations (10 passive, 10

active, 10 passive) were imposed under three loading conditions to elucidate phase specific effects of ankle loading: load during hip extension (EXT), load during hip flexion (FLX), and no loading (NL). Peak hip torque and root mean square (RMS) EMG of the rectus femoris (RF), gluteus maximus (Gmax), and medial hamstrings (MH) were analyzed in flexion and extension.

A significant difference (repeated measures ANOVA,  $P < 0.05$ ) in peak hip torque was observed for the SCI group only, with means for EXT and FLX greater than for the NL condition (Figure 1). Analysis of individual contrasts between conditions showed that peak hip torque and RF and Gmax EMG were significantly different for only FLX vs. NL while MH EMG was significantly different for both EXT vs. NL and FLX vs. NL.

These findings suggest that ankle loading may be necessary to achieve optimal hip muscle activation during gait training in SCI, particularly during body-weight supported training.

**Figure 1.** Hip position, torque, and EMG data for the last 5 passive and first 5 active cycles from one SCI subject. For SCI, torque and EMG were greater for both loading conditions as compared to no loading.



Acknowledgements: This work is supported by the Falk medical Trust and the GAANN fellowship program

# Non-contact Robotic Assessment of Upper Limb Movements

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**Keywords:** robotic rehabilitation, cerebral palsy, therapeutic robotics.

In recent years, robot-assisted rehabilitation has gained momentum as a viable means for improving outcomes for therapeutic interventions. Such therapy experiences allow controlled and repeatable trials and quantitative evaluation of impairment metrics. Typically though these robotic devices have been focused on adult-based rehabilitation, although recently, there has been growing interest in providing solutions for children (Krebs et al. 2009, Frascarelli et al. 2009). In these traditional robot-assisted rehabilitation studies, participants are required to perform goal-directed movements with the robot during a therapy session. This requires physical contact between the participant and the robot to enable precise control of the task, as well as a means to collect relevant performance data. Without the use of the robotic system, traditional means of collecting relevant performance data (or ground truth with respect to participants) involves using monitoring devices (ranging from video cameras to Vicon motion capture systems) in which therapist carefully analyze video sequences after a session. As such, robot-assisted rehabilitation not only provides a means to improved outcomes but reduces the therapist workload associated with patient assessment.

Unfortunately, due to a number of factors (including cost, safety, operator training requirements, etc.) these robotic devices are not yet at a stage ready for wide-spread adoption, either in the clinical setting or in the

home environment. To overcome this limitation, our research focuses on designing robotic devices for rehabilitation applications that utilize non-contact means of therapy (Brooks 2009). Such devices have shown promise in social interaction studies involving play with children with autism (Scassellati 2007), yet have had limited use in therapy experiences focused on children with motor impairments.

In this work, we discuss a novel method for automated robotic assessment of participant reaching patterns. The primary focus is to provide intervention for children with cerebral palsy (Chen 2009). We specifically present an approach which incorporates real-time vision techniques based on 1) isolating human arm movements from noisy background data through the use of a motion history imaging technique, 2) scaling extracted arm movements to a normalized range of operation through the use of a dynamic-time warping algorithm, and 3) identifying arm boundary conditions and body alignment vectors using random sample consensus. We provide results of our method applied to 20 participants and compare with ground truth data extracted from a motion capture system. By integrating these methods, we are able to extract movement parameters that enable us to determine Fugl-Meyer assessment metrics such as ROM, velocity, and smoothness ratios. This enables us to develop a non-contact robotic approach for assessment of upper limb movements.

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# Does robotic locomotor training influence the fundamental locomotor pattern in post-stroke?

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**Keywords:** Locomotor training, EMG, inter-joint coordination, vertical ground reaction forces, Lokomat<sup>®</sup>

Locomotor training (LT) is proposed to offer the requisite task-specificity to promote locomotor recovery for persons with neurological dysfunction. The efficacy of robotic (RLT) LT continues to be debated. The majority of studies to date report only effects on spatiotemporal parameters, including gait speed. Here we examined kinematic, kinetic, and muscle activation patterns during walking to determine whether LT affects the fundamental locomotor pattern in persons post-stroke.

Data were collected from 16 participants ( $57 \pm 14.37$  yrs; 13 male) with chronic ( $4.21 \pm 1.93$  yrs) poststroke hemiparesis at self-selected speed (SSWS) and 10 non-disabled controls who walked at SSWS and 2-3 slower speeds. Participants were studied prior to and following 12 30-minute sessions of LT (RLT/MLT: n=8/8). RLT was provided by a Lokomat<sup>®</sup> enabled to operate up to 5km/h. Participants trained at either slow (<2.5km/h; n=8) or fast (>2.5km/h; n=8) speeds. 3D kinematics, kinetics and EMG were obtained during overground walking. All data were normalized to the gait cycle and compared between post-stroke and healthy individuals at matched speeds. *EMG*: (RLT/MLT: n=6/8) Surface EMG was obtained from 8 muscles (TA, MG, SO, RF, VL, BF, SM, GM). Integrated EMG was calculated by gait phase. *IJC*: (RLT/MLT: n=6/6) Inter-joint coordination (IJC) was quantified by evaluating the

participant to control difference scores of the centroid location of hip-ankle angle-angle plots. *GRF*: (FAST/SLOW: n=7/6) Vertical ground reaction force (vGRF) peaks (F1, F2, F3) were used to calculate loading (F2/F1) and unloading (F2/F3).

Highlights of our findings to date include improved EMG and IJC following RLT. Bilateral changes in EMG corresponded with more appropriate patterning specific to gait functions: Non-paretic (NP) improvements in TA and GM corresponded with loading response and late swing. Paretic (P) improvements in BF suggest improved terminal knee stability during the transition to single-limb support while decreased RF activity prepared for the stance-to-swing transition. Improved IJC, evidenced by concurrent hip-ankle contributions were equally distributed across legs (NP: 4/6 hip-ankle; P: 6/6 hip, 3/6 ankle). Additionally, fast training produced improved loading (NP: 4/7; P: 5/7) and unloading (3/7 B).

Taken together our findings suggest improvements resulting from RLT lead to reacquisition of a coordinated locomotor pattern as evidenced by more appropriately timed EMG and improved IJC. Additionally, fast training improved vGRF. The ability of the RLT environment to safely enable fast training speeds, suggests its clinical value to promote normalization of the loading pattern.

# Interlimb influences: Role of non-paretic leg during walking post-stroke.

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**Keywords:** Hemiparesis, Lokomat.

Hemiparesis following stroke is typically considered a unilateral motor control problem of the paretic leg. However, it has been well established that the neural circuitry for locomotion is bilaterally organized. Evidence from animal and humans demonstrate bilateral deficits post-stroke. Previous work in pedaling demonstrated that due to disruption of the normal task-dependent suppression of interlimb influences, the paretic motor pattern is more impaired in bilateral pedaling than in unilateral paretic leg pedaling. This study aims to understand the motor output of the non-paretic leg as compared to healthy individuals. Specifically, we sought to understand whether non-paretic leg participation improves or impairs the performance of the paretic leg during walking.

One individual with chronic hemiparesis (female, 60 years) and one similarly aged healthy control subject (male, 54 years) participated in the study. Walking trials were conducted in the Lokomat robotic orthosis at the self-selected speed and matched speeds for both the subjects respectively. Guidance forces (GF) were changed for different trials: Trial 1=100% GF on both legs, Trial 2= 100% GF on paretic leg, minimum tolerated GF on the non-paretic leg, Trial 3= 100% GF on the non-paretic leg and minimum tolerated GF on the paretic leg. Bilateral surface EMG was recorded from six lower extremity muscles. Integrated EMG activity

over the gait cycle and the percentage duration the muscle was 'ON' over the gait cycle was calculated.

Preliminary analysis (more analysis is in progress) revealed that when the paretic leg is in the biomechanically controlled environment, all the six muscles recorded had reduced magnitude of integrated EMG activity and increased percentage duration of activity in the gait cycle in the non-paretic leg as compared to the healthy control subject walking a similar speed. For the individual with hemiparesis there was somewhat deterioration in the paretic leg muscle activity (percentage duration worsened in 3 muscles integrated activity in 3 muscles) due to influence of the non-paretic leg as compared to similar condition in healthy control subject.

These results demonstrate that both the integrated EMG activity and duration of muscle activity over the gait cycle is altered in the non-paretic leg post-stroke as compared to healthy control subject, suggesting bilateral involvement post-stroke. Furthermore, non-paretic leg tends to worsen the muscle output of the paretic leg, illustrating lack of the suppression of interlimb influences (Kautz et al 2005). This emphasizes the inclusion of non-paretic leg and bilateral tasks in the rehabilitation.

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# Combining electrophysiological assessment of motor control after neurological injury with robotic measures

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**Keywords:** Brain Motor Control Assessment (BMCA), electromyography, L-Force, L-Stiff.

Spinal cord injury (SCI) leads to a wide spectrum of both neurological deficit and residual motor control that is not easy to fully characterize or measure. Furthermore, it is often difficult to measure neurological recovery resulting from therapeutic intervention after injury or to know how to adjust those therapeutic interventions to gain greater improvements.

Functional scales describe the ability for the SCI patient to interact with their environment and provide for their own care but they do not reveal much about the mechanisms by which those skills recover or whether that recovery is due to any neurological plasticity. Other scales, like the ASIA impairment scale, characterize the integrity of certain anatomical pathways by scoring the magnitude of perception of sensory stimuli and the ability to voluntarily contract individual muscles. This scale, and electrophysiological tests such as evoked potentials, test conduction of signals across the level of SCI more than they do the processing of those signals to generate functional or dysfunctional motor activity below the level of injury.

The brain motor control assessment (BMCA) was designed to characterize and quantify supraspinal influence on infra-injury spinal neural circuitry (1,2), essentially describing residual motor control. The assessment consists of recording multi-muscle EMG below the level of injury and comparing the pattern and magnitude of activity between injured individuals and an averaged "normal" across a spectrum of test procedures that include voluntary relaxation, reinforcement maneuvers, voluntary muscle contractions, passive ranging, reflex testing and voluntary suppression.

This BMCA can characterize residual supraspinal control where none was noted on physical exam and it can quantify the extent to which residual motor control is of an abnormal pattern (dysnergias) or magnitude (hypo- or hypertonia) or both and it could be used to track neurological recovery over time or with a therapeutic intervention.

The BMCA is often performed in the supine position when some brainstem-spinal pathways are less active (vestibulospinal) and the examiner cannot measure the mechanical outputs of the patient's neuromuscular system nor the mechanical features of movements he imposes on the patient during the testing.

We have begun to develop a version of the BMCA that can be carried out in the Lokomat. First, this permits studying residual motor control in the upright position, a position in which most SCI patients function. Second, the mechanical measurement tools of the Lokomat, namely L-ROM, L-Force and L-Stiff, can be used to measure aspects of both the patient's capacity and the examiner's technique. The mechanical measures of the patients neuromuscular output can then be compared with the electrophysiological measures of spinal neural circuitry activity (muscle activation) associated with those movements.

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# Does re-established reciprocal stepping pattern EMG from treadmill training transfer to over ground walking in iSCI? Data from a case study

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Introduction: Locomotor training (LT) has been shown to promote recovery of reciprocal locomotor EMG patterns after spinal cord injury (SCI). Under attenuation, or absence, of supraspinal inputs, it is generally agreed that the recorded EMG patterns are elicited by spinal central pattern generators (CPG). Higher treadmill/stepping speeds, corresponding with physiological walking speeds, are hypothesized to augment the presence and amplitude of spinally-mediated EMG patterns. To date, it has been possible to conduct (LT) only at speeds up to 2.5km/h. LT using the assistance of a robot (RLT) facilitates attainment of physiological walking speed and maintenance of this higher speed for extended periods. Here we investigated the effect of increased walking speed to physiological levels (up to 5km/hh) on the emergence and amplitude of reciprocal locomotor EMG patterns. Further, because it is unclear to what extent CPG activation during LT influences the capacity for volitional activity during overground stepping, our second goal was to explore the extent to which CPG activation during RLT generalizes to volitional EMG activity during overground walking.

Methods: The participant was a 49 yo male, non-ambulatory 2 years s/p an iatrogenically-induced SCI (sub-T11). While he was classified as AIS C according to the International Standards for Neurological and Functional Classification, he had not regained function to the extent that can normally be expected for this patient group. The participant completed two 6-week blocks of RLT (Lokomat®) (4x/wk). He was instrumented with EMG once weekly. A manually supervised detection algorithm (Matlab) was used to identify EMG activity.

Results: During the 5<sup>th</sup> week of LT, a reciprocal EMG pattern emerged during RLT and EMG was also observed during overground walking. EMG amplitudes

increased non-linearly with higher walking speeds with more increase in amplitude per unit of speed increase between 2.5 and 5km/h. Functionally, the subject improved from being non ambulatory (WISCI-0) to being able to walk 10m with KAFO's between parallel bars (WISCI-9), to standing freely with KAFO's and eventually to step overground using KAFO's and a walker. These functional results have been maintained >2 years after LT.

Discussion: It appears that in this previously non-ambulatory individual, it was possible to activate the CPG through LT at physiological walking speeds, even 2 years after injury, and that to a certain degree he was able to transfer the improvements from RLT to overground walking. Our result suggests that LT-induced changes affect not only the CPG but also allow supraspinal inputs to engage residual spinal pathways.

# A Tongue-Controlled Robotic Arm for Environmental Access and Motor Rehabilitation

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**Keywords:** assistive technology, motor rehabilitation, robotic arm control, tongue drive system.

**Tongue Drive System (TDS)** is a tongue-operated wireless, unobtrusive assistive technology designed for people with severe disabilities. TDS translates volitional tongue movements to user-defined control commands by detecting the position of a small magnetic tracer, the size of a lentil, secured on the tongue. The tongue commands can be used to control a wide variety of devices in users' environments to improve their quality of life (Huo and Ghovanloo, 2010). TDS can also be used to control functional electrical stimulators (FES) to restore lost motor function or directly operate prosthetic devices during motor rehabilitation. The natural capabilities of the tongue, including flexibility, quick response, robustness, and non-invasive accessibility can give TDS the benefits of safety, accuracy and efficiency over existing EEG/EMG-based and implantable prosthetics control technologies.

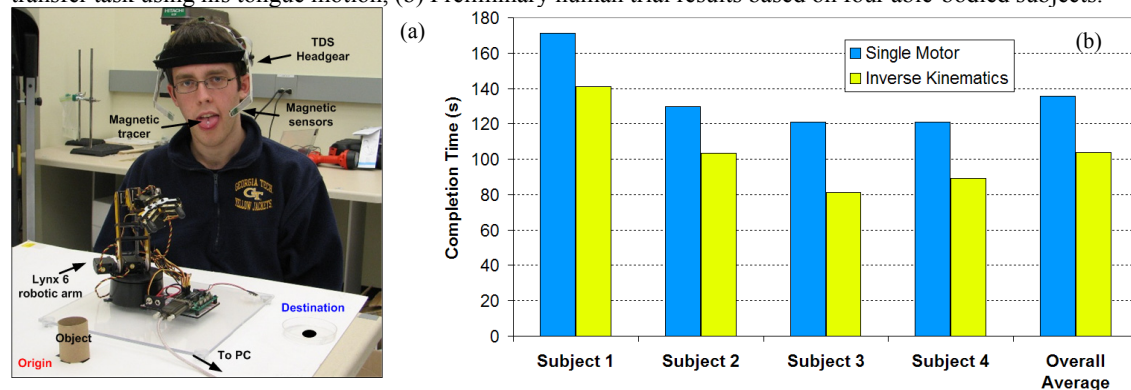
The objective of this work is to explore and demonstrate the feasibility of using TDS to control a small commercial robotic arm with six degree of freedom, which can eventually

be replaced by users' own prosthetic arms during motor rehabilitation.

A customized TDS-robotic arm control interface with two control mechanisms: single motor and inverse kinematics based control, has been implemented and tested. Preliminary results based on a human trial with four able-bodied subjects indicated that the users were able to use TDS to control the robotic arm to accomplish simple tasks, such as moving an object from its original position to a certain target (Fig. a). As indicated in Figure 1b, the average task completion time was 135.7 s and 103.7 s for single motor and inverse kinematics control methods, respectively. Based on these results and the subjects' feedback, it was determined that the inverse kinematics based control method is more efficient, intuitive, and user-friendly than the individual servo control method.

We are now working on a new experimental setup, in which the performance of the TDS-controlled robotic arm will be evaluated by using a 3D out-to-center Fitts' law style task.

**Fig. (a)** An able-bodied subject wearing the TDS headset to control a Lynx-6 robotic arm to complete an object transfer task using his tongue motion, **(b)** Preliminary human trial results based on four able-bodied subjects.



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This work was supported in part by the National Science Foundation award CBET-0828882 and Rockwell Collins Inc.

# A comparative study of 4 methods for determination of cane length in stroke rehabilitation for gait restoration

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**Keywords:** Cane, Cane length, Stroke, Rehabilitation, Gait

**Objective:** to evaluate standardized methods for cane length determination in stroke patient.

**Aim:** to compare 4 methods for cane length determination (Greater trochanter to ground, wrist crease to ground, Patient's preferred cane length as well as cane that keep elbow angle 30° -40° degree flexion) regarding their effects on postural controlling mechanisms and gait parameters.

**Subjects:** 40 male hemiplegics who are using canes during their daily living activities constituted the subjects of this work. The mean Age, weight, and height were 58.9 years, 88.5 Kilograms, 1.66 meters respectively and the mean duration of their illness was 49.2 months.

**Methods:** Postural stability parameters (Center of gravity projection on the base and total balance score) as well as gait parameters (walking speed, gait index, cadence, and stride length) were determined while using a single point cane with 4 tested cane lengths.

**Results:** The use of canes improved all parameters of gait as well as postural stability. Patients failed to determine the appropriate cane length by themselves. The use of anatomical landmarks (Greater trochanter or distal wrist crease) for determination of cane length proved to be not sensitive in the determination of cane length. Cane length that keeps the elbow in 30°-40° flexion proved to be the most effective.