Podium Presentation at the International Society of Biomechanics/ American Society of Biomechanics (2005):
The Effects of Locomotor Training on Neural and Muscle Activation.

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INTRODUCTION

There is generally limited quantitative kinematic, and electromyography (EMG), regarding the effect of Locomotor Training using body weight support Treadmill Training (BWST) for an extended period of time on a person with ASIA B classification. The objective of this case study is to determine the effects of Locomotor Training using body BWST on kinematics, neural, and muscle activation changes for an individual with an incomplete SCI (ASIA B), one year post injury.

METHODS

The participant (male, 26 years, ASIA B, no motor function below level of injury, injury level C6) trained for 35 sessions of Locomotor Training (T1), stopped training for 8.6 weeks, and recommenced training for another 62 sessions (21 weeks) (T2). Before T1 (PRE-T1), and before T2 (MID) kinematic and EMG data were collected [at 60% and 40% body weight support (BWS), treadmill speed at 1.6 mph]. After T2 (POST-T2) was completed, kinematic and EMG were collected bilaterally for 60%, 40% and 20% BWS. A 6-camera Vicon system (sampled at 60Hz) was used to collect kinematic data. Spherical reflective markers were placed on right and left second and fifth metatarsal, calcaneous, tibial tuberosity, femoral epicondyle, greater trochanter, anterior inferior iliac spine, posterior inferior iliac spine. EMG was recorded using surface EMG for left and right medial gastrocnemius (L/R G), tibialis anterior (L/R TA), rectus femoris(L/R RF) and bicep femoris(L/R BF). EMG was collected at a bandwidth of 10-600 Hz, and sampled at 1500 or 1560 Hz. Raw EMG signals were filtered at a bandwidth of 30-150 Hz, full-wave rectified, then root mean squares (RMSs) were calculated over a 120ms window (2). EMG data was processed using MATLAB (MathWorks Inc., Version 6.1). Calculation of sagittal plane segment motion for the thigh, shank and foot was determined using MATLAB (MathWorks Inc., Version 6.1). Limb kinematics were calculated in the local moving plane with calculation of orientation angles for each segment relative to the right horizontal (3). 6-8 gait cycles were analyzed per condition.

RESULTS AND DISCUSSION

After training, EMG firing patterns were consistent to kinematic profiles at the hip and knee. Before training the EMG firing profiles were not. Higher EMG amplitudes were observed after training [Pre vs post (60%BWS): LBF: 19.64±.23 vs 43.76 ±5.10uV; LR: 19.64 ± 1.36 vs 43.76 ± 1.13uV; LG:3.96 ± 1.29 vs 23.73 ± 1.01uV].

For the LRF, LBF, and LTA the EMG activity were more rhythmical and less tonic after the first series of Locomotor Training sessions (Figure 1). Significantly, at PRE-T1, the LBF was firing for most of the gait cycle (GC) [i.e., mean burst duration (BD) was 88.1 ± 6.1% of the GC] whereas at MID, the mean BD decreased to 55 ±15% of the GC and at POST-T2 its BD decreased further to 41±15%. In general, the BD for the LTA and LG at MID and POST-T2 decreased with increasing load.

Further, there was a positive linear response in mean EMG amplitude to bodyweight (BW) load. At mid, mean EMG amplitudes for all muscles (LR, LBF, LTA, and LG) increased with loading from 40% to 60% BW and at POST-T2 the mean EMG amplitude for LG (at 40%, 60%, and 80% BW load) also increased. The results for LBF and LTA were more variable. Both of these muscles showed a decrement in mean EMG RMS amplitude (from 40% to 60% BW load) followed by an increase (from 60% and 80% BW load).

All of these results demonstrate the positive neural and muscle activation changes that occur after Locomotor Training for an individual with an incomplete SCI (ASIA B, 1-year post).

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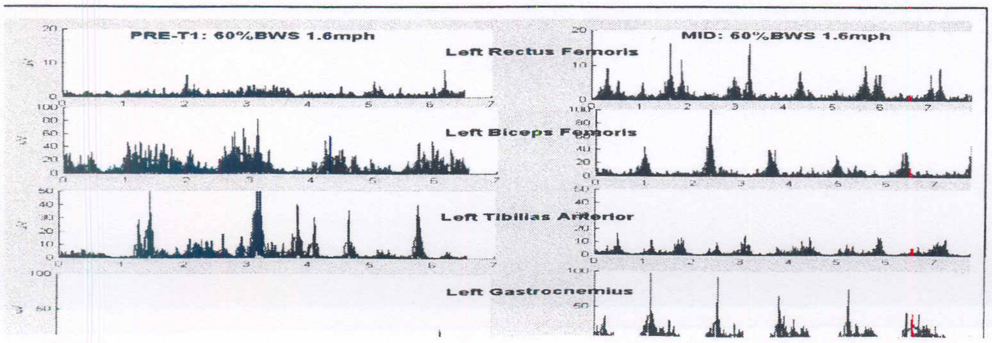

Figure 1. At PRE –T1 & MID. Rectified EMG and EMG RMS amplitude (uV) versus time (sec) for 5 gait cycles LRF, LBF, LTA,

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Presentation at American Society of Biomechanics, 2005

The Effects of Locomotor Training on Muscle Activation.

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Introduction

- ASIA C & ASIA D (Motor Function)
- ASIA B's or 100% wheel chair reliant

Hypotheses

Locomotor Training (LT) vs. Traditional Rehabilitation

Standing Over ground / Walking

Muscle activity (amplitude and timing)

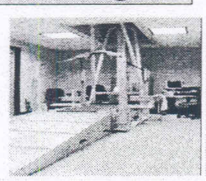
Overview

- 18-55 years, ASIA B, C (C6-T6)
- > 1 year Post Injury :100 % Wheel Chair Reliant
- Bone density measurement:
  T-score less than -2.5

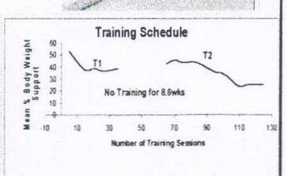
Individual: Male, 26 years, ASIA B, (C6), 1 year post.

Overview: Training

- Randomized 2 groups:
  - Traditional
  - LT w/BWST, Over ground



Individual: 1 hr Training, 35 sessions, 62 sessions



Testing

- Pre/Mid/ Post intervention:
  1.6 mph : 60%, 40%, & 20% (Training BWS)
  - Kinematic Data:
    6 - 7 camera 370 Vicon system (60Hz)
  - EMG data :
    bandwidth of 10-600 Hz
    sampled at 1500 or 1560 Hz.
    filtered at a bandwidth of 30-150 Hz, Full WR (RMS) were calculated over a 120ms window

Intervention

Early

Late

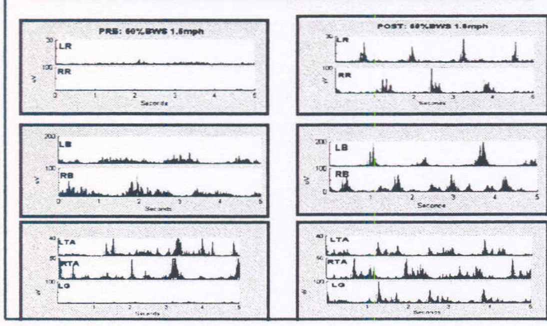
Results: Kinematics, EMG & Functional Gains

Experimental Kinematics

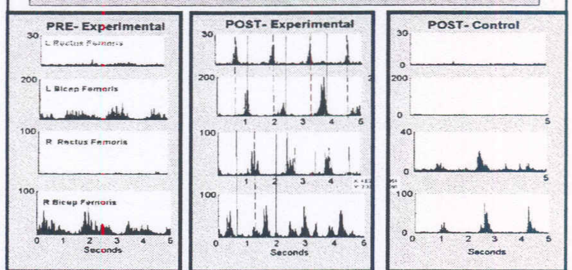
SCIWALK

1 experimental
ASIA B , C6, 1 year Post

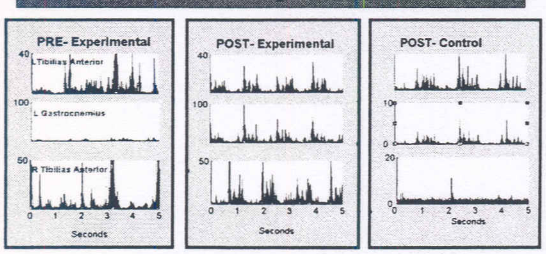
EMG - Experimental: ASIA B: 1.6mph 60% BWS



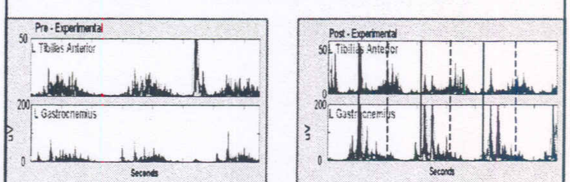
Experimental vs Control ASIA B: 1.6mph 60% BWS



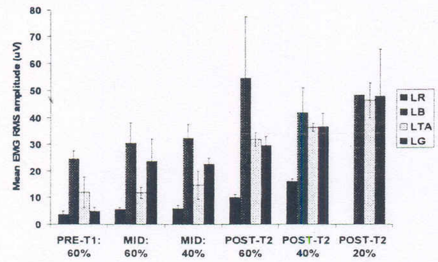
Experimental vs Control ASIA B: 1.6mph 60% BWS



Experimental ASIA B PRE (60% BWS, 1.6mph) vs. Post (0% BWS,1.6mph) :

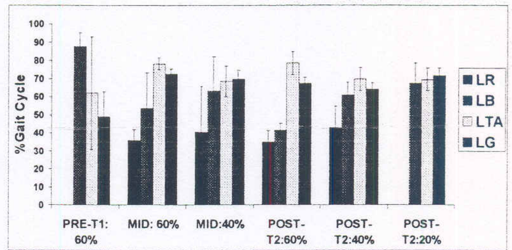


Mean EMG RMS amplitude



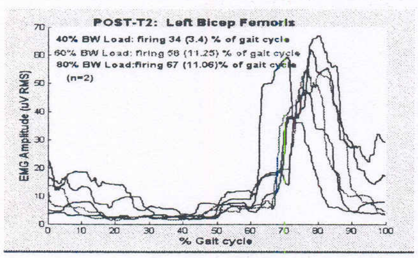
n=10 - 12 steps

Burst Duration after Training



n=10 - 12 steps

With Loading Increase Burst Duration



Experimental Group

Summary

Experimental:

- After Muscle Timing in PHASE w/ Leg
- After training Amplitudes increased
- With ↑↑↑ loading EMG BD and Amplitude

Functional Outcomes

- ASIA B Standing w/Walker
  Experimental: 20 (±2) min
- ASIA B ⇨ C
- Trunk Control

Limitations

- Trainers (step to step)
- Training Time

Future

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Autonomic Nervous System Response to Locomotor Training with Body Weight Supported Treadmill Walking in Individuals with Incomplete SCI

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Abstract—**Progressive locomotor training (LT) with repetitive stepping using Body Weight Supported Treadmill Training (BWSTT) allows persons with a Spinal Cord Injury (SCI) to ambulate. The foundational nature of the Autonomic Nervous System (ANS) on the spinal cord advocates Heart Rate Variability (HRV) research in LT. LT proposes a method of regaining normal ANS function by exploiting the plastic properties of the spinal cord. This study will be the first to analyze performance of the ANS through HRV comparing LT to traditional therapy in incomplete SCI. When this study is completed, 36 participants will have been randomly assigned to an experimental BWSTT group or the control group. Preliminary data related to 4 participants (n=2 experimental and n=2 control) with chronic C6 tetraplegia (≥1 year post injury) classified as incomplete ASIA B and C. The analyses currently under discussion include traditional time and frequency methods including heart rate and systolic blood pressure power spectrums, and the sequencing method of calculating the Baroreceptor Sensitivity Index (BRSI). The data remains insignificant though visual inspection of the data suggest more parasympathetic activation of the LT participants vs. traditional therapy.**

I. Introduction

Spinal central pattern generators (CPG)s have demonstrated an ability to learn specific behavior through repetition. Progressive LT with repetitive stepping using BWSTT and manual assistance allows persons with a SCI to ambulate. LT consists of 3 components: 1) Step training on a treadmill while receiving overhead support and manual assistance; 2) Overground walking training to emphasize deficits during treadmill training; 3) Community ambulation training using an assistive device. Though detrimental effects of SCI on the ANS are well documented, reinnervation of the spinal cord and accompanying quantitative measures of ANS improvement remain elusive. The analyses currently under discussion include traditional time and frequency methods including heart rate and systolic blood pressure power spectrums, and the sequencing method of calculating the BRSI. Since individuals with SCI demonstrate CHD risk factors greater than able-bodied peers, this methodology would be ideal in identifying changes in these risk factors for this disability group.

HRV Time and Frequency Analysis: Once the peak-detected inter-beat-interval (IBI) data is calculated for time-series data, analysis may continue in the time domain or frequency domain. In the time domain two variables have been shown to correspond strongly with changes in parasympathetic activity: the percentage of consecutive inter-beat intervals varying by more than 50ms (pNN50) and the root mean square of the IBI standard deviation (RMSSD). For frequency domain calculations, the Fourier Transform of the IBI signal results in the basic spectral analysis where the low-frequency (LF) range (0.05 - 0.15 Hz) power spectrum represents sympathetic and parasympathetic activity and the high frequency range (0.15 - 0.40 Hz) solely parasympathetic activity. The three variables pNN50, RMSSD, and HF HRV represent parasympathetic nervous system activity over short time recordings [1].

LF SBP Power Spectrum: Spinal sympathetic neurons are distributed in cord segments from T1 to about L2. Spinal cord injury drastically impairs normal variations in blood pressure by restricting central sympathetic nervous system activity. Some have theorized that the Systolic Blood Pressure (SBP) variability power spectrum, known as Mayer Waves, indicates central sympathetic outflow and is calculated over the LF range from 0.07 - 0.14Hz.

BRS Sequencing: Another measure of cardiac autonomic regulation involves the baroreflex, the central nervous system's regulation of short-term arterial pressure changes, through a measure called Baroreflex Sensitivity (BRS). Increased pressure detected through blood vessels triggers baroreceptors in the vessel walls, which decrease cardiac outflow by decreasing heart rate and vascular resistance. The opposite is true of a decrease in vascular pressure. Calculation of the spontaneous BRSI through the sequencing method: A ramp of either three consecutive increasing or decreasing systolic blood pressure peaks is first identified and the change in heart rate is monitored in response to this blood pressure change.

Physiological benefits accompany increased baroreceptor sensitivity. BRS decreases with cardiovascular conditions such as hypertension, coronary artery disease, congestive heart failure, has been found to predict death in post-myocardial infarction, and is also related to age and exercise capacity [2].

II. Research Design and Methods

When this study is completed, 36 participants (18-55 years, between 1 and 3 years post injury, with an incomplete spinal injury (C6-T6) will have been randomly assigned to an experimental BWSTT group or the control group. Further autonomic testing will include seated paced breathing, standing, and walking protocols along with time-frequency and partial coherence data analyses.

The experimental group will have received BWSTT using a pneumatically controlled body weight support (BWS) system capable of evenly offloading body weight during stepping. Optimal training for the participants involves progressively decreasing BWS and increasing velocity while maintaining proper kinematics.

The control group will have received traditional physical therapy consisting of upper body weight training cardiovascular training, and gait training. Both groups will train for 60 sessions, 3 times per week.

Preliminary data related to 4 participants (n=2 experimental and n=2 control) is presented. All four individuals are chronic C6 tetraplegia (≥1 year post injury) classified as incomplete ASIA B and C.

Data Collection: All autonomic seated data was collected at Baseline, Mid (12 weeks), and Post training regardless of the training group. ECG, respiration, and blood pressure were sampled at 500Hz for 5 minutes of spontaneous breathing. The Colin 7000 arterial tonometer was used to record continuous blood pressure.

BRS sequences have traditionally been calculated with a lag of 0 referring to the number of heartbeats between the initial blood pressure ramp and the resultant change in heart rate [3]. Though lag 0 may calculate BRS most accurately in the able bodied population, some SCI persons fail to register any lag 0 sequences but do present lag 1 and 2 sequences. In this analysis BRSI was calculated by finding the average BRSI for each sequence regardless of its lag 0, 1, or 2 designation.

III. Results

Time and Frequency Domain: By visual inspection the pNN50 of both BWSTT participants decreases from Baseline to Mid tests then increases from the Mid to Post tests. This behavior is mimicked when plotting the RMSSD data for the BWSTT participants. No clear trend in pNN50 or RMSSD was present for the control participants. This preliminary data shows a decrease in parasympathetic activity from Baseline to Mid tests followed by an increase from Mid to Post tests for the BWSTT participants. This data lacks statistical significance due to the small group sizes. The frequency domain data confirms the decrease in parasympathetic output at the Mid test for the intervention group while the control group remained fairly constant throughout the testing protocol.

LF SBP Power Spectrum: The graphical data does not confirm an increase in sympathetic activation from the Baseline to Post tests.

BRS Sequencing: By visual inspection only one BWSTT participant showed moderate gains in BRS from Baseline to Post tests while the other LT participant showed no gains at all. BWST2 recorded 0 sequences for Baseline and Post tests. One control participant showed modest gains in BRS while the other decreased. BRS activity closely matched parasympathetic nervous system activity as measured by pNN50 for 3 out of 4 subjects (R=0.97).

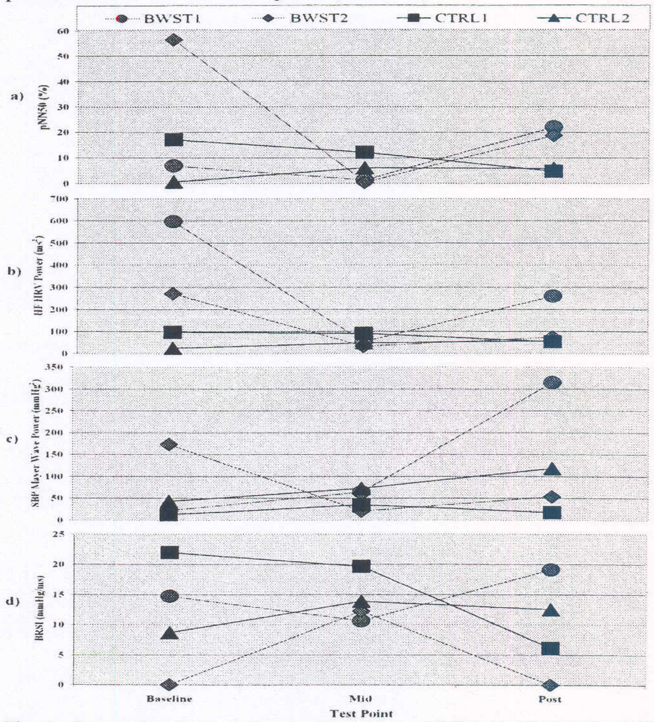

Fig. 1: Comparing Intervention to Control a) pNN50, b) HF HRV, c) SBP Mayer Wave, d) BRSI

IV. Conclusions

Through an exercise training regimen parasympathetic nervous system activity will increase over time. Though this increase will likely be seen in both groups, the shift toward parasympathetic activity should be more pronounced in the LT group. One explanation of the shift toward a more sympathetically driven system during the training protocol could be that during time-periods of intense physical training parasympathetic activity will withdraw [4]. Postural exercise in both groups suggests a correlation between BRSI and parasympathetic activity. These preliminary data are intended to introduce the types of analyses being performed on the ANS with BWSTT and may prove to be a useful technology to quantify gains ANS changes as a result of LT with BWSTT. More subjects will be needed to confirm or refute statistical significance.

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Podium Presentation: The American Council of Rehabilitation Medicine, 2005:
The Effects of Locomotor Training on Bone Density and Body Composition.

Gail F Forrest, PhD (Kessler Medical Rehabilitation Research and Education Corporation, Sue Ann Sisto, PhD, Steven Kirshblum MD, Janina Wilen, MS, Quin Bond, BS, Scot Bentson, MS , Pierre Asselin, MS, Susan Harkema, PhD

Objective: To test the hypothesis there will be an increase in bone and muscle (in lower extremity) after Locomotor Training (LT) using body weight support on a treadmill (BWST) for individuals after incomplete SCI compared to traditional (TT) rehabilitation intervention. **Design:** Randomized, controlled study. **Setting:** Human Performance and Movement Laboratory.
Participants: Four participants (2 controls, 2 experimental, ASIA B, 1 year post injury, 100% wheelchair reliant, unable to stand at pre) were randomly assigned to either LT or TT. **Interventions:** Participants completed 60 sessions (1 hr training, 3x/ week). TT included gait training (GT). Before and after training DEXA scans for total body (TB), femoral neck (FN) were done.
Main Outcome Measures: Bone Mineral Density (BMD) for TB and FN. Fat mass (FM), lean body mass (LM) as percentage of total tissue and shank circumference (SC).
Results: Minimal decrease in TB BMD (LT:2±1%;TT:.2±.2 %), and in FN BMD (LT:14±4.2%;TT 5±2%). Body weight increased (LT:9.1±3.4%; TT:11±10%). Minimal change in LBM (legs) for LT(.8%±6%) and decreased for TT (5.4±3.5%) SC increased for LT (3±12%) and decreased for TT (6±12%).
Conclusions: Decreased decrement in bone potentially occurs after LT and TT (with GT) for individuals with an incomplete SCI. For one participant an increase in LBM was shown after LT.
Key Words: Bone Loss, Body Composition Rehabilitation.

Podium Presentation: American Paraplegia Society, 2005:
The Effects of Locomotor Training on Muscle activation, Body Composition, Bone Density.

Forrest, GF PhD, Sisto, SA PhD, Kirshblum S MD, Wilen, J MS, Bond, Q BS, Bentson, S MS , Harkema, S PhD

Background: Locomotor Training (LT) facilitates functional walking recovery among chronic incomplete SCI with ASIA Impairment scale C and D. There is limited quantitative kinematic, electromyography (EMG), bone mineral density (BMD), and body composition research regarding the effect of LT for an extended period of time on an a person with ASIA B classification in improvement of functional recovery.
Case: To determine the effects of LT (1 hr training, 3x weeks, 97 sessions) using body weight support Treadmill Training on kinematics, neural, muscle and BMD changes for an individual with an incomplete SCI (one year post injury, ASIA B, 100% wheelchair reliant, unable to stand). Before and after training dual energy x-ray absorptiometry scans for total body (TB) and hip were used. Kinematic and EMG data were collected bilaterally for 60% and 40% treadmill speed at 1.6 mph.
Results: Minimal decrease in TB BMD (0.01%), and a decrease in femoral neck BMD (1.009vs0.827 gm/cm^2). The femoral neck decreased its bone mineral content (21%).

Body weight increased (12%). Fat and lean body mass (LBM) in the arms and trunk increased. In the legs LBM increased (15%) and fat decreased (6%). Shank circumference increased (by 2.6 cm).

After training, EMG firing patterns were consistent to kinematic profiles at the hip and knee. Before training the EMG firing profiles were not. Increased mean EMG amplitude [LBF: 19.64±.23vs43.76 ±5.10uV; LR:19.64±1.36vs43.76 ±1.13uV; LG:3.96±1.29vs23.73 ±1.01uV] and changes in burst durations reflected a stepping pattern, functionally more appropriate to locomotion.

Tolerance for standing using a walker (assistance at the pelvis and knees) overground on a flat surface improved. After training, standing was documented to be 20 min (± 5.3 min). Three months post, able to stand in a walker at home for one hour with the help of one assistant.
Conclusion: Positive neuromuscular and bone changes potentially occur after LT for an individual with an incomplete SCI (ASIA B, 1 year post injury). Gains in neural activation were shown to transfer to functional outcomes.