The following are the abstract proceedings from the 2018 Conference in Human Movement Variability Podium Presentations

Knee Proprioception impairments post Total Knee Arthroplasty

Abderrahman Ouattas[1], Katlyn Nimtz[1] & Brian Knarr[1]
[1]Department of Biomechanics, University of Nebraska at Omaha, Omaha, NE USA
email: aouattas@unomaha.edu, web: https://www.unomaha.edu/college-of-education/cobre/

Presentation Preference: [**Podium**]

INTRODUCTION

While Total Knee Arthroplasty (TKA) surgery ideally eliminates pain, and restores functional performance[1], the procedure replaces biological tissues with a prosthetic knee joint, which may contribute to a reduced joint sense and proprioception. Pre-TKA, reduced knee proprioception due to OA has been shown to result in abnormal gait patterns and dynamic lower limb asymmetry that, in turn, leads to further OA progression[2]. Mechanisms responsible for these manifestations post-TKA, however, are unclear.

Previous studies have shown contradictory results regarding the relationship between TKA and loss of proprioception[3,4]. While proprioception is typically assessed through single joint position sense, balance has been used as a surrogate to measure proprioceptive ability post-TK[5] making a broad generalization of current research difficult. Due to the contradictory findings in literature, the main objective of this study is to assess if knee proprioception impairments are present post-TKA. In addition, we still lack a reliable method to measure proprioception. Thus, the second objective aims to determine the correlation between single joint proprioception measurement and multi-joint balance assessment.

METHODS

9 post-TKA (at least 3 months post-surgery) and 4 healthy age matched community dwelling participants participated in the study (Table 1). To assess knee proprioception, participants performed the threshold to detect passive motion (TDPM) using the Biodex located at the Biomechanics Research Building. Using equation (1), Proprioceptive abilities were considered deficient if the thresholds were greater than 45% of that of the unaffected knee and healthy controls[6].

$$Deficiency = \frac{Sx - NSx}{Sx} \times 100 \quad (1)$$

To assess balance, participants performed the sensory organization test (SOT)[7] using the NeuroCom (Natus Medical Incorporated, San Carlos, CA). Sample Entropy (SampEn) was extracted for the medial-lateral (ML) and anterior-posterior (AP) center of pressure (COP) for each condition and each trial. Data were processed using Matlab (MathWorks; Natick, Massachusetts). Pearson correlation coefficients were calculated to assess the relationship between TDPM and SOT.

RESULTS AND DISCUSSION

TKA participants demonstrated proprioceptive deficiency during flexion trials (Deficiency= 48.03%), but failed to show mean deficiency during extension trials (Deficiency =36.22%) (Figure 1). Conversely, Healthy controls did not show proprioception deficits during either extension (Deficiency= 0.39%) or flexion (Deficiency= 3.64%) trials.

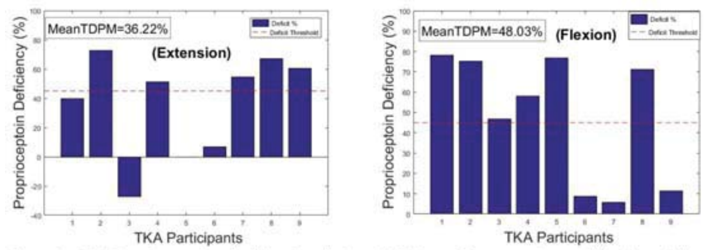

Figure 1. TKA Proprioceptive deficiencies during TDPM test for extension and flexion trials.

Flexion TDPM and AP SampEn COP showed significant correlations in the TKA group (r^2 C1=0.59, C2=0.93, C3=0.67, $p<0.01$), during conditions demanding somatosensory information (Conditions 4, 5, and 6 of the SOT). Extension TDPM and ML SampEn COP of condition 6 shown significant correlations (r^2= 0.92, $p<0.05$) in the control group.

CONCLUSIONS

Thus far, our results indicate deterioration in knee proprioceptive abilities post-TKA. Moreover, sample entropy of the AP COP may be an indicative of poor proprioceptive abilities post-TKA, but the SOT may not be an appropriate measure of proprioception as no additional correlations were seen between the two measures. Moving forward, we aim to understand the role of proprioception on dynamic balance post-Op.

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Table 1: Participant Demographics

Participants	Months post-TKA	Age (years)	Height (m)	Weight (kg)	BMI (kg/m²)	Gender
Post-TKA	18.33	63 ± 3	1.70 ± 0.09	89.11 ± 16.54	31.03 ± 6.79	6 F 3M
Control	-	67 ± 5	1.65 ± 0.07	68.35 ± 14.68	24.85± 5.01	3 F 1M

COORDINATION AND BRAIN ACTIVITY CORRELATES OF UPPER-LIMB PROSTHESIS USE

James Pierce[1], Drew Dudley[1], David Salazar[1], Keaton Young[1], Walker Arce[1,2] & Jorge Zuniga[1]
[1]Department of Biomechanics, University of Nebraska at Omaha, Omaha, NE USA
[2]Department of Electrical Engineering, University of Nebraska at Omaha, Omaha, NE USA
email: jepierce@unomaha.edu, web: https://www.unomaha.edu/college-of-education/cobre/

Presentation Preference: **Podium**

INTRODUCTION

There are increasing numbers of children with traumatic and congenital amputations or reductions. The Centers for Disease Control and Prevention estimates that about 1,500 babies are born with upper limb reductions every year. Of these, only one in 9,400 children is considered for prosthetic fitting. Despite this increasing number of pediatric limb reductions, motor control and coordination in this population is still largely unexplored due to high cost and complex needs introduced by children's small size, constant growth, and psychosocial development [1, 2].

Advancements in computer-aided design (CAD) and additive manufacturing offer the possibility of designing and manufacturing prostheses at a very low cost [2]. By utilizing these technologies, exploration of underlying control mechanisms in novice amputees can be performed.

The purpose of the present investigation was to determine the influence of upper-limb prostheses and prosthetic simulators on brain activity in the motor cortex and bimanual coordination compared to typically developing control children.

METHODS

Children with upper limb deficiencies (ULD) (n = 8) and two groups of typically developing, age- and sex- matched children (n = 8 controls, n = 8 prosthetic simulator users) performed reaching and gross motor tasks to assess function and brain activation.

Inclusion criteria included boys and girls from 3 to 17 years of age with unilateral upper-limb reductions. Exclusion criteria included any medical conditions that would be contraindicated with the use of our 3D printed prostheses prototypes.

The study was approved by the UNMC Institutional Review Board. All parents and children were informed about the study and parents signed a parental permission.

Eight healthy controls performed functional tasks with their hands, and eight used a prosthesis simulator on their non-preferred hand. A timed bimanual reaching task was used to assess overall coordination, [3] and the "Box and Block" test determined overall manual gross dexterity. [2] Functional Near Infrared Spectroscopy (fNIRS) was used to determine magnitude and location of brain activity during these functional tasks. [4] Various questionnaires will also be utilized to assess overall satisfaction, quality of life (QoL), embodiment/agency, and prosthesis usage.

RESULTS AND DISCUSSION

Preliminary data from two subjects (a 16-year-old girl and a 14-year-old boy with congenital reduction of the left and right hands, respectively) indicates that after using the prosthesis for 1 month (2 hours/day minimum), there was a reduction in movement duration for the affected hand using the prosthesis. This resulted in an increased synchrony between the affected (with prosthesis) and non-affected hands. (Figure 1) Furthermore, the overall motor control strategy during the post-test was to lead with the affected hand, thereby decreasing the speed of the non-affected hand in order to improve synchrony. This indicates that one month of practice with a prosthesis improved bimanual coordination (movement duration and synchrony of hands) during a functional bimanual motor task.

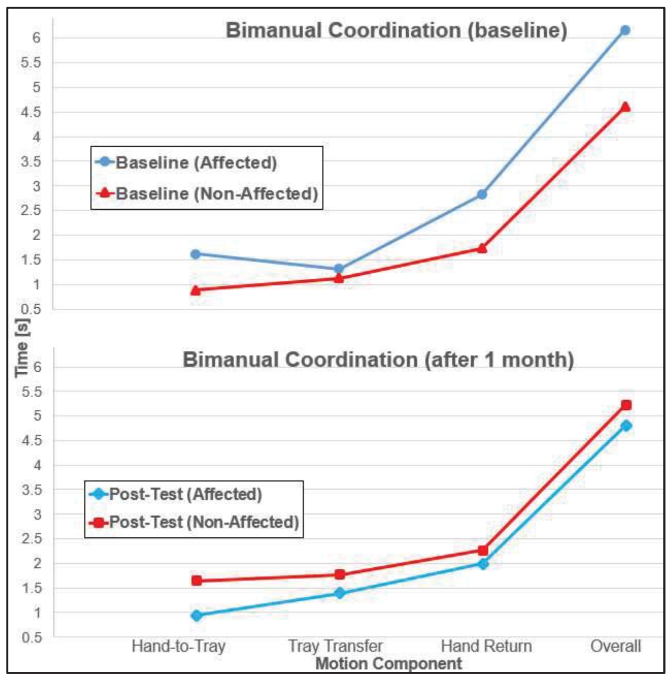

Figure 1. Improvement in movement duration and synchrony of hand movement during a functional bimanual coordination test after 1 month of using a prosthesis (n=2).

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SAMPLE ENTROPY DIFFERENCES IN STATIC POSTURAL CONTROL IN INDIVIDUALS WITH CHRONIC ANKLE INSTABILITY

Adam B. Rosen[1], Jennifer Yentes[2], Melanie L. McGrath[1], Mukul Mulkherjee[2], & Sara A. Myers[2]
[1]School of Health and Kinesiology, [2]Department of Biomechanics, University of Nebraska at Omaha, Omaha, NE USA
[3]Health and Human Performance Department, University of Montana, Missoula, MT USA
email: arosen@unomaha.edu, web: https://www.unomaha.edu/college-of-education/health-kinesiology/

Presentation Preference: [**Podium**]

INTRODUCTION

In the United States, 23,000 people sprain their ankle daily and over half of those will fail to seek appropriate medical treatment [1]. Chronic ankle instability (CAI) is a long-term pathological sequelae of ankle sprains, developing in almost half of those who sprain their ankle [2]. While single-limb balance deficits are traditionally considered a hallmark characteristic of CAI, many studies have failed to find changes in traditional linear measures of postural control during single-limb stance. While traditional linear measures are primarily employed to quantify movement, assessing quality or motor variability may provide valuable insights into the health of a system especially during balance. Therefore, the overall goal of our project was to assess non-linear measures of postural stability during a single-limb stance in persons with CAI, compared to copers and controls.

METHODS

Eighty-six participants volunteered for this study. CAI participants had a history of moderate-severe ankle sprain, frequent giving way episodes, and a Cumberland Ankle Instability Tool score of <24 (n=30, 13M, 17F, age= 22.3±2.7yrs, mass= 76.9±19.1kg, height= 171.6±9.5cm, CAIT= 17.5±4.5). Ankle sprain "copers" had a history of moderate-severe ankle sprain, but reported no giving way episodes, and a Cumberland Ankle Instability Tool score of >28 (n=26, 12M, 14F, age= 22.2±2.6yrs, mass= 71.4±12.9kg, height= 172.9±10.3cm, CAIT= 28.8±1.1). Control participants had no history of sprain or giving way and a CAIT>28 (n=30, 14M, 16F, age=22.1±2.5yrs, mass= 75.6±13.9kg, height=171.9±9.6cm, CAIT =29.9±0.3).

Participants stood on a single leg on a force platform for 60sec with eyes open. Center of pressure (CoP) excursion in the anterior-posterior (AP) and medial-lateral (ML) directions was collected at 1000Hz.

Sample entropy (SampEn), a non-linear method of assessing time-series regularity, was calculated in each direction from the CoP data. SampEn calculates the probability that a pattern will repeat within a time series of data. Higher values indicate less regularity and more randomness, while lower values indicate greater regularity and pattern repetition. An analysis of variance (ANOVA) with Tukey's post-hoc testing was conducted to determine differences in SampEn between the groups (p<0.05).

Cohen's d effect sizes and it's 95% confidence interval were calculated to determine the magnitude of differences.

RESULTS AND DISCUSSION

A significant main effect for group (p=0.024) was observed for SampEnAP. The CAI group demonstrated significantly greater SampEnAP compared to the control group (p=0.018, Cohen's d=0.73 95% CI: 0.21-1.25, Figure 1). No differences in SampEnML were observed between groups (p=0.594, Table 1).

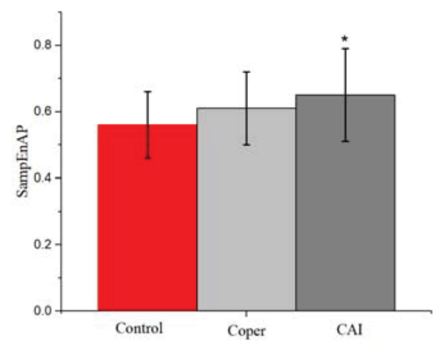

Figure 1: SampEnAP in the control, coper and CAI groups. *indicates significance p<.05

This may indicate that single-limb stance postural control in individuals with ankle instability is less organized and less regular in terms of structure of the movement, particularly in the anterior-posterior direction. Previous research has similarly observed higher levels of variation at the ankle in CAI participants during a stop-jump [3].

CONCLUSIONS

Participants with CAI demonstrated more irregular AP CoP patterns compared to healthy controls, suggesting an altered strategy to maintain upright postural control. The mechanism behind this organizational phenomenon is unclear and explored further to improve treatment protocols in those with CAI.

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Table 1: Sample entropy values in the control, coper and chronic ankle instability groups. *indicates significance p<.05

Group	SampEnAp*	SampEnML
Control	0.56 ± 0.10	0.67 ± 0.12
Coper	0.61 ± 0.11	0.70 ± 0.10
Chronic Ankle Instability	0.65 ± 0.14	0.68 ± 0.15

A NOVEL TASK TO DECREASE STEP WIDTH VARIABILITY IN OLDER ADULTS

Andreas Skiadopoulos, Katherine Allen & Nicholas Stergiou
[1]Department of Biomechanics, University of Nebraska at Omaha, Omaha, NE USA
email: askiadopoulos2@unomaha.edu, web: https://www.unomaha.edu/college-of-education/cobre/

Presentation Preference: [**Podium**]

INTRODUCTION

Walking is the most common fall-related activity among older adults [1]. Also, older adults experience greater step width variability when walking [2]. Importantly, increased step width variability during walking has been found to be a strong predictor of fall risk and incidence [3]. Therefore, an intervention for reducing increased step width variability may consequently reduce fall risk for older adults. We propose that lateral stepping training program will improve walking in older adults by reducing the increased step width variability to normal values.

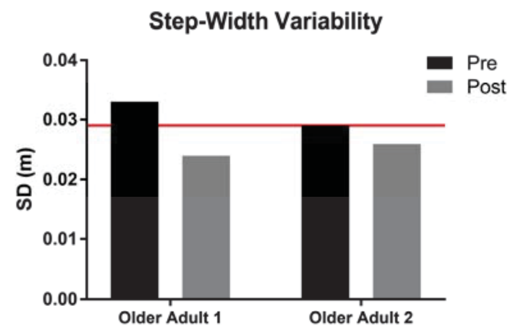
METHODS

Healthy community-dwelling older adults aged 65+ underwent an initial screening treadmill walking for 3 minutes at self-selected comfortable speed (baseline speed). Two older adults with increased step width variability (> 0.029 cm) were recruited and underwent an overground lateral stepping training three times a week for six weeks, resulting in 18 sessions. Each session consisted of 30 minutes of lateral stepping. Participants step laterally across a 10m section on an indoor track, changing direction at the ends thus alternating lead and lag limbs. Three minutes of lateral stepping alternated with at least one minute of rest. The participants strived to increase speed as they progressed through the 18 sessions. Following the six weeks of lateral stepping training, participant's step width variability was measured: participants selected a new comfortable walking speed and performed 3 minutes walking on the treadmill at their new, post-training, self-selected comfortable speed.

During the data collection on the treadmill, participants wore retroreflective markers on the top of the second metatarsal (MT) joint and posterior heel. Continuous motion of feet was tracked by a 17-camera high-speed motion capture system (Motion Analysis Corp.) at 100 Hz. The raw 3D marker trajectories were smoothed using the GCVSPL algorithm [4]. Foot position was calculated as the center point between a heel and MT marker (Visual 3D, C-Motion, Germantown, MD). Step width was determined as the medial-lateral distance between the locations of the sequential left and right mid-footsteps. Step width variability was calculated as the standard deviation of step width.

RESULTS AND DISCUSSION

The six-week lateral stepping intervention decreased the step width variability in the older adults during the typical forward walking on the treadmill (Figure 1). Moreover, the new comfortable walking speed that the older adults chose after the six-week training was greater than baseline speed: (Older Adult 1: baseline speed = 1.0 m/s, Post-training speed = 1.4 m/s; Older Adult 2: baseline speed = 0.8 m/s, Post-training speed = 1.38 m/s) Our early results point that the six-week lateral stepping intervention results in improvement in walking mobility by decreasing step width variability and increasing gait speed.



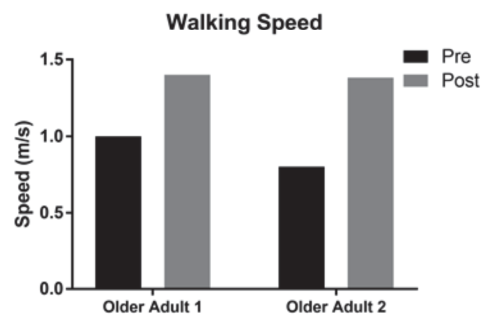


Figure 1: Step variability during typical walking on the treadmill was assessed at baseline (Pre) and post-training speed (Post). The six-week lateral stepping intervention decreased the step width variability and increase gait speed.

CONCLUSIONS

The lateral stepping training results in reduced step width variability during forward walking in older adults. Lateral stepping exercise program is simple, time and cost effective and can start from day one at home without the need for supervised training sessions.

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The following are the abstract proceedings from the 2018 Conference in Human Movement Variability Poster Presentations

`EFFECT OF LIMB DOMINANCE ON LIMB SYMMETRY INDEX IN STRENGTH AND JUMPING MEASURES

Dillon Anderson[1], Brooke Farmer[1], Kimberly Turman[3], Dimitrios Katsavelis[2], Jenny Bagwell[1], & Terry Grindstaff[1]
[1]Department of Physical Therapy, Creighton University, Omaha, NE USA
[2]Department of Exercise Science and Pre-Health Professions, Creighton University, Omaha, NE USA
[3]GIKK Orthopedics, Omaha, NE USA
email: GrindstaffTL@gmail.com, web: https://spahp.creighton.edu/research/rehabilitation-sciences-research-laboratory

Presentation Preference: [**Poster**]

INTRODUCTION

Functional tests are one tool used by physical therapists to determine return to sport after anterior cruciate ligament reconstruction (ACL-R), with the goal of obtaining limb symmetry on all tasks prior to return to sport. Limb dominance, prior to reconstruction, is not often considered when looking at limb symmetry. Quadriceps maximum voluntary isometric contraction (MVIC) and single leg forward hop are two tasks commonly used to assess return to sport readiness. The purpose of this study was to determine if limb dominance has an effect on a subject's limb symmetry index (LSI) in quadriceps MVIC or single leg forward hop distance in subjects 5-12 months after ACL-R.

METHODS

This study included 40 subjects (24 female, 16 male; dominant limb injured: 13, non-dominant injured: 14, age= 20.17 ± 5.27 years, height= 174.79 ± 9.23 cm, mass= 71.84±14.53 kg, time since surgery = 5.62±1.26 months) with ACL-R. Dominance was determined by which leg the subject would jump off of for maximal height. An isokinetic dynamometer (Biodex) was used to obtain MVIC (Nm). Subjects performed a standardized warm up of six isometric contractions (50-100%) to orient them to testing procedures. After the warm up, participants completed three to six maximal isometric contracts with the largest MVIC used to calculate the limb symmetry index (LSI). Participants then performed a single leg hop for distance. Three to six repetitions were completed on each leg. Maximal forward hop distance was used to calculate LSI. The uninvolved limb was tested first followed by the involved limb for both MVIC and single leg forward hop testing. The LSI was calculated by dividing the involved limb by the uninvolved limb. Independent t tests were performed and statistical significance was set at priori $p < 0.05$.

RESULTS AND DISCUSSION

The results of this study show that limb dominance does not have a statistically significant (p-value= .201, effect size= .5 (moderate)) effect on MVIC between limb dominance groups. However, when looking at the limb symmetry index, there are noticeable differences in MVIC between a non-dominant injured limb (.77±.22) and a dominant injured limb (.88±.21). When comparing limb dominance's effect on single leg forward hop, the results are close to statistical significant (P-value= .051, effect size of .78 (large)) when comparing the forward hop distance between groups. Despite insignificant statistical differences there are differences between non-dominant injured limb LSI (.82±1.5), and dominant injured limb LSI (.93±.11). (Figure 1).

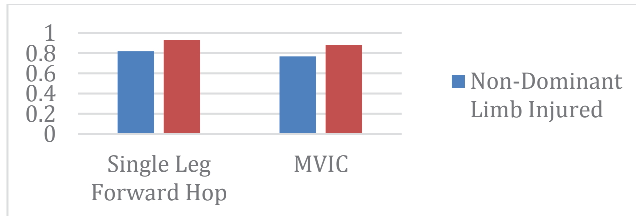

Figure 1: Comparison of LSI values between dominant and non-dominant injured limbs in MVIC and single leg forward hop

CONCLUSIONS

Limb dominance does have an effect on LSI in both quadriceps MVIC and single leg forward hop distance. Six months (the average time of our study sample) is considered an appropriate time for return to sport and dependent the injured limb, dominant or non-dominant, the LSI can have an in the decision if an athlete is considered ready to return to sport by meeting the 90% LSI criteria or not. This should be considered when testing athletes for return to sport following ACL-R rehabilitation.

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EFFECTS OF TIMING AND MAGNITUDE OF WAIST PULLING ASSISTANCE ON METABOLIC COST AND JOINT MECHANICS

Prokopios Antonellis, Arash M. Gonabadi & Philippe Malcolm
Department of Biomechanics and Center for Research in Human Movement Variability,
University of Nebraska at Omaha, Omaha, NE USA
email: pantonellis@unomaha.edu, web: http://coe.unomaha.edu/brb

INTRODUCTION

Walking is a fundamental skill and the primary gait of humans. During walking, the need to generate various muscular forces creates a metabolic demand. A previous study found that an assistive horizontal force at 10% of a subject's body weight, pulled forward at the waist, could result in a 47% reduction in metabolic energy consumption [1]. Such reductions suggest that this type of assistance could be helpful in assistive devices for individuals with limited mobility, where the high metabolic cost of ambulation limits their participation in society. However, there is limited information regarding the kinematics or mechanical work of walking with a horizontal assist force that would aid in understanding the reduction in metabolic energy use.

The objective of this study is to investigate the relationship between waist pulling force, actuation timing, and metabolic cost during walking over a broad range. A second aim is to determine the optimal assistance parameters that created the greatest reduction in metabolic cost.

METHODS

Participants will walk on a treadmill at 1.25 $m \cdot s^{-1}$. Assistive forces will be applied using a cable-pulling robot (Humotech, Fig. 1) tied to a waist belt. The waist belt is instrumented with a load cell. A control algorithm in Simulink will be developed to apply a spline-shaped force during a specific partition of the stride cycle and with a specific peak force.

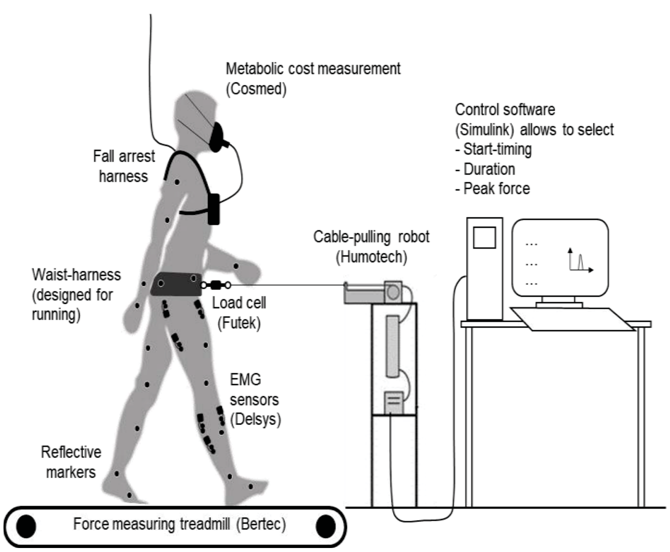

Figure 1. Experimental setup.

Thirty assistance force profile conditions will be tested that are random combinations of the following parameter options:
- Onset timings: 0, 10, … to 90 % of the stride cycle.
- Assistance duration: 10, 20 and 30%.
- Peak assistance force magnitude: 0, 5, 10 and 15% of body weight (BW). Values were chosen based on [2].

Each condition will last two minutes. This is sufficient to calculate the steady state metabolic cost based on recent methods [3, 4]. Participants will wear a face mask connected to a portable gas analysis system (Cosmed). Kinematic data will be captured using an 8-camera VICON motion capture system. Surface electromyography (EMG) of the major muscles of the lower limb will be measured with bipolar surface electrodes and wireless transmitters (Delsys). A mixed-model ANOVA will be used to create a surface fit, and to determine the effects and interaction effects of waist pulling actuation timing and force across all conditions (Fig. 2).

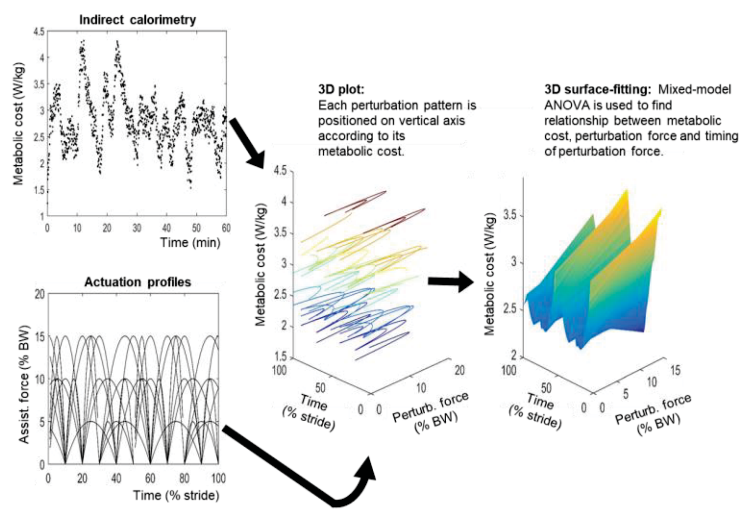

Figure 2. Conditions and statistical fitting.

ANTICIPATED RESULTS AND DISCUSSION

The optimal assistance onset timing and average force levels from this study could guide the development of a powered walker that may be of benefit to individuals with limited mobility. A powered walker which senses user feedback and intelligently provides a forward force at appropriate times (i.e., when the COM accelerates forward) may reduce metabolic cost to a greater extent compared to constant waist pulling assistance.

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SUPERVISED WALKING EXERCISE THERAPY IMPORVES GAIT BIOMECHANICS IN PATIENTS WITH PERIPHERAL ARTERY DISEASE

[1]Molly Schieber,[2,3]Iraklis I. Pipinos,[2,3]Jason M. Johanning,[2]Holly K. DeSpiegelaere,[1]Benjamin Senderling,[2]Cassidy Berlin,[1]Sara A. Myers

[1]Department of Biomechanics, University of Nebraska at Omaha, Omaha, NE, USA[2]Omaha Veterans' Affairs Medical Center, Omaha, NE, USA[3]University of Nebraska Medical Center, Omaha, NE, USA

Presentation Preference: **Poster**

INTRODUCTION

Peripheral artery disease (PAD) is a common manifestation of atherosclerosis affecting the blood flow to the legs. The most common presentation of PAD is intermittent claudication; a condition in which when the patient walks the metabolic demands of the lower limbs exceed the limited supply of blood, causing ischemia, and exercise- induced discomfort and decreased walking ability [1]. Walking exercise is the first line of treatment in patients with claudication with the best results achieved in patients undergoing supervised exercise therapy for at least three months. Supervised walking exercise results in increased maximum walking distances comparable to those seen following surgical revascularization, despite the fact that blockages remain [2]. With this study we tested the hypothesis that supervised exercise training of patients with PAD improves walking distances in association with improved gait biomechanics.

METHODS

Forty-seven patients (age: 69.2 ± 7.0; height (m): 1.75 ± 0.7; mass (kg): 89.4 ± 18.7) were seen at the Omaha Veteran Affairs Medical Center vascular clinic and evaluated by one of two vascular surgeons. Patients had no history of previous revascularization and were absent of all musculoskeletal and neurological symptoms that could limit gait in addition to PAD. Informed consent was obtained from all subjects prior to starting the twenty-four week (three sessions per week), supervised walking exercise therapy. Each session included a 5 minute warm-up, 50 minutes of intermittent exercise on a treadmill, and 5 minutes of cool down activities.

All patients underwent gait analysis before and immediately following exercise therapy. First patients performed the Gardner Max Walk Test [4]; a progressive, graded treadmill protocol at 0.89 m/s that begins at 0% grade, and increases by 2% every two minutes. Initial claudication distance was recorded as the first indication of claudication pain from the patient. The total distance patients were able to walk before stopping because of pain was recorded as maximum claudication distance.

After sufficient rest, each participant was instructed to walk over a 10-meter pathway at a self-selected pace to commence the overground trials where marker trajectories (Motion Analysis Corp, Santa Rosa, CA) and ground reaction forces (kinetics;600Hz;AMTI force platforms) were recorded. Each patient was tested before (pain free) and after (pain) the onset of claudication pain. After completing the pain free condition, symptomatic claudication pain was induced by completing the six minute walk test [3]. All patients at baseline experienced a "moderate to severe level of pain" in the leg used for analysis. Immediately after, patients returned to the walkway to perform the walking trials for the pain condition. Five walking trials were collected from each leg of the participants in both conditions.

RESULTS AND DISCUSSION

Our hypothesis was partially supported. Both walking distances (Figure 1) and several, but not all, gait biomechanics variables significantly improved following supervised walking exercise therapy.

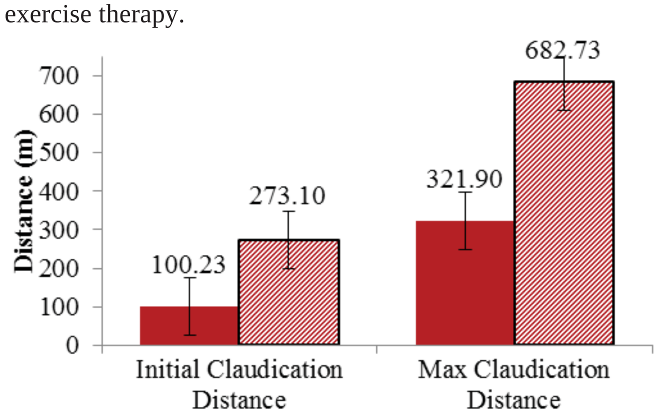

Figure 1: Walking distances before (pre) and after (post) the exercise intervention therapy

Weakness in the posterior compartment muscles of the calf is a consistent and key factor underlying the gait adaptations patients with PAD experience at baseline [4]. Improvements in ankle power during single support and the propulsion phase of gait before and after the onset of claudication pain reflect improvements in this area.

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THE ASTRO XO™ EXOSKELETON ALTERS ANKLE KINETICS IN HEALTHY INDIVIDUALS

[1] Blake Beier, [1]Angel Gonzalez, [1]Erica Hedrick, [1]Jeff Patterson, [1]Corbin Rasmussen, [1,2,3]Iraklis Pipinos, [1]Sara Myers

[1] The University of Nebraska at Omaha, Omaha, NE, USA
[2]University of Nebraska Medical Center, Omaha, NE, USA
[3]Omaha VA Medical Center, Omaha, NE, USA
email: bbeier@unomaha.edu, web: cobre.unomaha.edu

INTRODUCTION

The ankle joint is one of the most important for walking, producing 35-45% of the summed ankle, knee, and hip positive mechanical work for each stride [1]. Ankle weakness results in reduced torque and power production, leading to slower self-selected speed. Slower preferred walking speed correlates with poorer physical function, health status, more disabilities, and increased medical-surgical visits. Many orthotic and exoskeletal devices have been created to restore proper ankle function by promoting ankle plantar flexion.

The ASTRO XO^{TM} Exoskeleton (AXO) is a passive, flexible device that promotes forward propulsion during stance, assisting plantar flexion and improving ankle range of motion (ROM) [2]. Increasing plantar flexor torque and ankle ROM has been suggested to improve gait deviations, such as walking speed [3]. While the AXO was originally designed to assist gait for people suffering from plantar fasciitis, it is our interest to see the AXO's effect on the ankle, especially during push-off, for pathological populations that have reduced ability to propel with the ankle.

First, we needed to establish how the AXO impacts gait in healthy individuals. Thus, this study assessed the effects of the AXO on ankle kinetics and kinematics for healthy, young individuals. We hypothesized that wearing the AXO will not affect the dominant leg ankle angle throughout stance phase, but will increase the peak ankle moment and peak ankle power due to the passive elastic components storing and returning energy.

METHODS

Four young, healthy individuals (3 males, 1 female, 23.25 ± 1.25 yrs, 75.5 ± 12.4 kg) walked for one minute with and without the AXO on their dominant leg. Using 3D motion capture and an instrumented treadmill, set to 1.25 m/s, ankle angle, moment, and power were measured during treadmill walking. Data was processed using Vicon Nexus tracking software and analyzed using C-Motion's Visual 3D. All variables were collected in the sagittal plane and were time normalized to stance phase of the gait cycle, and all kinetic variables (ankle moment and power) were normalized to subjects' body mass in kilograms. The average of each subject was taken and used as a representative sample of the effects from the AXO device.

RESULTS AND DISCUSSION

As hypothesized, ankle range of motion showed very little differences when wearing or not wearing the AXO. The peak plantar flexion angle while wearing the AXO produced a 1.50% decrease. Peak dorsiflexion demonstrated a 0.51% increase while wearing the AXO.

Kinetic variables showed relatively small changes. Ankle power data showed that energy was generated, though eccentric contractions, earlier in stance with the AXO compare to ankle power without the AXO, seen in Figure 1.

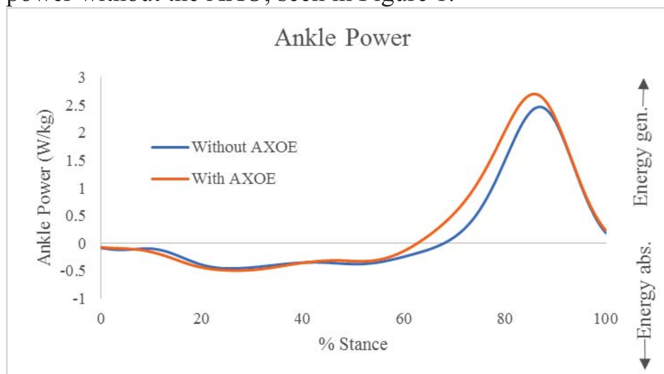

Figure 1: Ankle power with the AXO (blue) and with the AXO (orange) during stance phase of gait.

Ankle power data showed that the AXO device produces an 8% increase in positive power compared to without the device. Additionally, ankle moment data showed that the AXO produces a 3.21% decrease in negative moment, and a plantar flexor torque earlier in the gait cycle.

CONCLUSIONS

The study demonstrated that our initial hypothesis that the AXO device does not produce significant changes in ankle joint angle was correct. Alternatively, our hypothesis that the kinetic variables of the ankle moment and power would increase while wearing the AXO was partially supported. Ankle peak moment decreased in magnitude while ankle power peak had a small increase that made peak energy generation occur earlier in stance.

Since the AXO device is designed to help individuals with decreased ankle power and moment production, a future study could repeat this experiment with people who need plantar flexor assistance. In that study, it is likely to see an even greater change in ankle moment and power with and without the AXO device.

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DEVELOPMENT OF A HOME-BASED SENSORY ORGANIZATION TEST

Lauren Bowman, Troy Rand, Takashi Sado, and Mukul Mukherjee
Department of Biomechanics, University of Nebraska at Omaha, Omaha, NE USA
email: lbowman@unomaha.edu

Presentation Preference: Poster

INTRODUCTION

Maintaining standing posture is a complex task that requires sensory input from several sensory systems: visual, vestibular, proprioceptive, and tactile. Aging and pathology, such as a stroke, can have detrimental effects on these systems, affecting an individual's ability to maintain stable posture. The current method for measuring sensory contributions to standing balance is the sensory organization test (SOT) utilizing the Neurocom balance device.[1] However, this piece of equipment is large, stationary, and expensive, limiting testing to a laboratory setting. The purpose of this study is to develop a Home-based Sensory Organization Test (HSOT) that is an inexpensive and portable alternative to the SOT.

Stroke is a serious problem in the United States and can result in long term disability.[2] Strokes may affect the visual, vestibular, and somatosensory systems, often resulting in asymmetric sensorimotor deficits. Currently, the Neurocom is used to detect these asymmetries by tracking the subject's center of pressure (COP) during standing balance tasks. The HSOT will also be used to measure COP and will be validated by comparing results to the clinical gold standard, the Neurocom balance manager. The goal of this research is to investigate the validity of the HSOT as an instrument to measure balance asymmetry in a group of healthy subjects and stroke survivors.

METHODS

Fifteen healthy, young and 15 stroke survivors will be utilized. Subjects will be excluded if they present any conditions that may affect the test. All subjects will complete six conditions of the SOT on the Neurocom balance manager.

1	2	3	4	5	6
Eyes Open	Eyes Closed	Eyes Open	Eyes Open	Eyes Closed	Eyes Open
Stable Platform	Stable Platform	Stable Platform	Moving Platform	Moving Platform	Moving Platform
Visual Surround	No Vision	Moving Vision	Visual Surround	No Vision	Moving Vision

Subjects will then complete the HSOT which consists of 24, one-minute trials. Subjects will stand on a Wii balance board in a comfortable side-by-side stance while the sensory systems are perturbed. The HSOT includes a combination of perturbations of four sensory systems: vision, tactile, proprioceptive, and vestibular. Each system will be perturbed individually with the tactile, proprioceptive, and vestibular systems being perturbed by tactors and the visual system being perturbed by a lab-designed VR environment setup in a Google Pixel phone and viewed using a VR headset (Figure 1).

RESULTS AND DISCUSSION

It is anticipated that the results of the HSOT will be validated with the results of the SOT. Both tests will perturb the visual, tactile, proprioceptive, and vestibular systems similarly enough to produce comparable results when analyzing the COP. When the visual feedback is removed or perturbed, participants will have an increased COP because the brain relies on the visual system to determine the bodies position in space. COP will also increase as more sensory systems are perturbed simultaneously because less reliable sensory information will be available to control balance. The various conditions that perturb the sensory systems will illuminate any deficits in the sensorimotor control of standing balance.

Fig 1. Subject utilizing the HSOT devices to measure balance.

Between the two populations that will participate in this study, we expect to observe limited balance deficits in the healthy young participants while detecting pathological balance deficits in the stroke survivor population. Healthy individuals have a greater ability to differentiate misleading or reliable sensory information which they then use to control their standing posture. Individuals with pathological balance deficits have more difficulties making the differentiation and therefore are less able to control their standing posture.

CONCLUSIONS

Developing the HSOT would allow the recreation of the quantitative output of the SOT in a home environment. It would also permit the direct assessment of the tactile and vestibular systems contributions to balance which are either not directly or indirectly measured with the SOT. The HSOT would provide a much more affordable and portable solution to screen and diagnose pathological balance deficits in a much larger population than the lab/clinic-based SOT allows. One current limitation is the need for a home visit by someone well versed with utilizing the different devices. However, it is anticipated that future versions of the device will be easy to use.

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ACKNOWLEDGEMENTS

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DESIGN IMPROVEMENTS ON A WEARABLE APPARATUS FOR SLIP PERTURBATIONS

Kyle Brozek[1] & Nathaniel Hunt[1]
[1]Department of Biomechanics, University of Nebraska at Omaha, Omaha, NE USA
email: kbrozek@unomaha.edu, web: https://www.unomaha.edu/college-of-education/cobre/

Presentation Preference: **Poster**

INTRODUCTION

Design of a wearable apparatus for slip perturbations will permit investigation of the reactive, rather than anticipatory recovery responses to slip perturbations. Slipping, which accounts for approximately 25% of all falls [1], must be addressed in any comprehensive fall-reduction intervention. Previous research demonstrates that falls can be reduced in the lab through training [2]. However, state of the art methods to produce slip perturbations either do not mimic the mechanical and sensory experience of a natural slip, or are predictable, because they reside at a fixed location within the laboratory. Training with predictable slip perturbations cannot discriminate between the effects of anticipatory and reactive responses on fall reduction. To investigate the reactive response to slip perturbations we have designed a Wearable Apparatus for Slip Perturbations (WASP). Since the WASP is always underfoot, the subject cannot predict when or where the slip perturbation will occur. Furthermore, remote triggering of the slip perturbation enables the experimenter to control the phase of slip-onset within the gait cycle. The first version of WASP is currently being used to determine the effects of slip-onset phase on recovery responses.

The second version of WASP is being developed to improve usability and experimental control. With WASP II we are making the following design improvements: (1) reducing the weight, (2) reducing the size, and (3) adding programmable, semi-autonomous slip triggering.

METHODS

Weight and size reduction for WASP II is being achieved by redesigning the slip triggering mechanism (Figure 1). The previous triggering mechanism used a powerful solenoid and battery pack worn at the waist. Force was transmitted along a Bowden cable down the leg to pull a pin at the shoe. This released a spring-loaded clipper which cut a line, releasing the low friction slipping outsole from the shoe. The redesigned triggering mechanism will be completely housed on the shoe.

Size and weight will be reduced in the new triggering mechanism by replacing the solenoid, battery pack, Bowden cable and spring-loaded clipper with a small line cutting mechanism with a custom printed circuit board that controls a nichrome heating filament connected to a commercial 9V battery. A custom cutting mechanism housing will be 3D printed minimize the footprint (Figure 1).

Programmable triggering will allow the experimenter to prescribe the phase of gait at which slip onset is to occur. Then, the WASP will use mediolateral strips of Velostat pressure sensors (Figure 1) and custom microcontroller code to determine the phase of gait, and semi-autonomous trigger the slip perturbation.

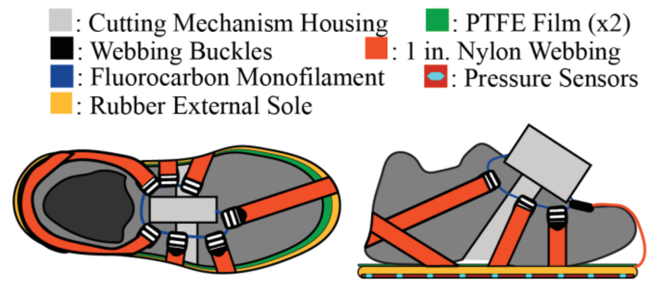

Figure 1: WASP II Design

RESULTS AND DISCUSSION

The new design will result in a substantial decrease of weight and size (Table 1). Total weight of the new triggering mechanism will be reduced by 62%. Total volume will be reduced by 87%. Footprint will be reduced by 66%.

Table 1: Size and Weight Reduction in WASP II

Device Iteration	Weight (g)	Volume (cm^3)	Footprint (cm^2)
WASP I	1,465	848	210
WASP II	554	111	74

Initial testing of the pressure sensitivity of Velostat indicates the minimum pressure for activation is approximately 6 pounds per square inch.

CONCLUSIONS

WASP II will substantially reduce size and weight, while allowing precise control of slip perturbation onset. This novel device will allow investigation of reactive responses to slips. Design improvements take the next steps towards future testing of an intervention and possible clinical translation of a biomedical device to reduce falling.

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THE EFFECT OF CONSONANT VS. DISSONANT AUDITORY STIMULATION ON GAIT VARIABILITY

Shawn Daley[1], Vivien Marmelat[1]
[1]Department of Biomechanics, University of Nebraska at Omaha, Omaha, NE USA
email: sdaley@unomaha.edu, web: https://www.unomaha.edu/college-of-education/cobre/

Presentation Preference: **[Poster]**

INTRODUCTION

Rhythmic auditory stimulation (RAS) has been a focus for motor rehabilitation and sensorimotor synchronization research in recent years. Research pertaining to movement pathologies such as Parkinson's Disease have shown that entrainment to an auditory rhythmic stimulus can increase gait speed and step length [1]. RAS is typically composed of an isochronous rhythmic structure, i.e., each beat is equally spaced from the next.

However, human gait is not isochronous: consecutive strides are not equally spaced but present fluctuations from one gait cycle to the next. These fluctuations exhibit a self-similar or fractal structure, potentially reflecting the adaptive capacities of the locomotor system [2]. Recent research embedding fractal fluctuations in auditory stimulation have shown that humans are capable of entraining to these rhythms and that the structure of stride intervals fluctuations tends to match the structure of inter-beat intervals [3].

While promising outcomes have been demonstrated in RAS using fractal metronomes, other components of the stimuli such as pitch and harmonic content have been largely ignored. In a repetitive pointing task, movement timing was affected by consonant vs. dissonant (i.e., 'pleasant' vs. 'unpleasant') auditory stimulation, even after the stimulus was removed [4]. It seems that the auditory system is tuned in to the biological relevance of consonant versus dissonant sounds. However, the possible impact of consonance and dissonance in the context of gait cueing is unknown. Furthermore, whether the effects seen during the synchronization phase with a fractal metronome are retained after the removal of the stimulus remains unexplored.

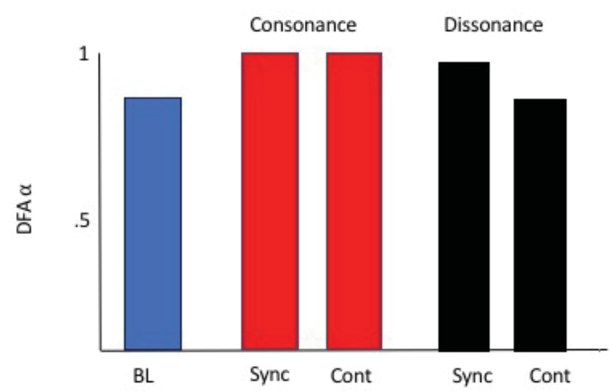
This project aims to investigate the effects of consonance and dissonance of a metronome and its impact on variability of gait during a synchronization phase and continuation phase. We make the hypothesis that the structure of stride intervals will match the structure of the metronome more closely with the consonant than the dissonant metronomes. In addition, we make the assumption that this 'complexity matching' effect will be sustained only after synchronization with a consonant metronome.

METHODS

20 healthy young adults will be recruited. The protocol for this experiment will begin with a baseline condition of 12 minutes walking at preferred speed on a treadmill to determine baseline dynamics of subject's gait. Subjects will then walk for two conditions (consonant or dissonant metronome) of 24 minutes each, with at least 10 minutes rest between them. Each condition will begin with 12 minutes of synchronization to the auditory metronome, followed by 12 minutes of continuation without any external stimuli. The main outcome will be the scaling exponent of stride intervals assessed with the detrended fluctuation analysis (DFA). A 2 (consonant vs. dissonant) x 2 (synchronization vs. continuation) repeated measures ANOVAs will be used to detect statistically significant differences ($p<0.05$).

EXPECTED RESULTS

We expect that consonant auditory stimulation will lead to an increase in DFA alpha values of stride intervals in both synchronization and continuation conditions, whereas continuation under dissonant auditory stimulation will see a decrease in DFA alpha values.



CONCLUSIONS

This study will be the first to determine the effects of auditory stimulation 'harmony' on the structure of stride intervals. Our findings will improve our understanding of sensorimotor synchronization with fractal rhythms and impact gait rehabilitation by providing the most optimal auditory stimulation to patients suffering from movement disorders such as Parkinson's disease.

Figure 1: Structure of stride intervals in the different conditions (expected results). BL indicates baseline walking dynamics on treadmill. Consonant (red) and Dissonant (black) bars indicate expected performance in synchronization (Sync) and continuation (Cont) phases.

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THE EFFECTS OF FOOTWEAR OUTSOLE GEOMETRY ON THE BIOMECHANICS OF WALKING USING SHOES WITH INTERCHANGEABLE OUTSOLES

Cory Frederick, Prokopios Antonellis, & Philippe Malcolm
Department of Biomechanics, University of Nebraska at Omaha, Omaha, NE USA
email: cmfrederick@unomaha.edu, web: http://coe.unomaha.edu/brb

Presentation Preference: Poster

INTRODUCTION

Metabolic cost can be influenced by walking on uphill and downhill gradients [1]. Walking uphill increases metabolic cost, while walking downhill decreases metabolic cost, but only to a certain point [1]. Previous research has shown that if a stair and a ramp have the same amount of rise, stairs will be the most metabolically optimal choice [2].

This study will examine how changing the outsole geometry of a shoe can affect the metabolic cost while walking. The weight, hardness, and stiffness of the shoe and outsole will be kept constant throughout this study.

The purpose of this study is to identify an outsole geometry that is metabolically optimal at different gradients. It is hypothesized that an outsole that resembles the gradient most, will be the most metabolically efficient for that gradient.

METHODS

Ten participants will be recruited and tested for this study. They will walk on a split belt treadmill at 10°, 0°, and +10° gradients, with the speed set at 1.0 m/s. Each treadmill gradient will test the five most optimal outsole angles for the grade that is being walked on.

The primary outcome that will be examined during this study is the metabolic effect these outsole geometries have on walking while on different gradients. Participants will wear a face mask connected to a gas analysis system that measures O_2 consumption and CO_2 production continuously (Cosmed). Each subject will have their resting metabolic rate measured with a resting condition, and the metabolic rate will be calculated using the Brockway [3] equation.

This study will also examine secondary outcomes. These outcomes include lower extremity joint angles and muscle activity. Participants will be wearing a full body suit that will include passive retro-reflective markers placed on the lower limbs. Kinematic data will be captured using an 8-camera VICON motion capture system. Surface electromyography (EMG) of the major muscles of the lower limb will be measured with bipolar surface electrodes and wireless transmitters (Delsys).

ANTICIPATED RESULTS AND DISCUSSION

From pilot tests, it is anticipated that the metabolic cost will be the lowest for the outsole that is most closely matched with the treadmill gradient. The lower extremity joint angles, at this most metabolically efficient outsole, could be closely related to the joint angles of the neutral outsole condition on the 0° gradient. It is expected that the EMG pattern will be closely related to the neutral outsole condition on the 0° gradient.

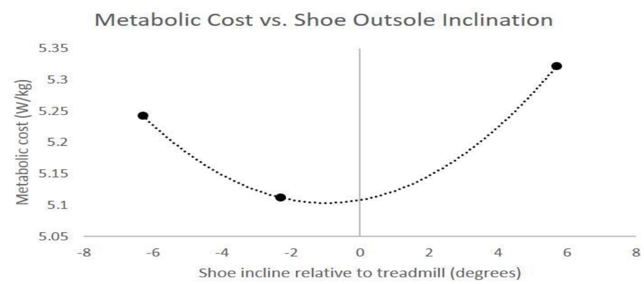

Figure 1: Potential metabolic rate results while walking on a +10° incline with different outsole geometries.

CONCLUSIONS

This study could potentially identify an optimal footwear design for certain activities. It could help design shoes that have adaptive inclination or declination where it is possible to attach an outsole for a certain activity. This could also help with the design of stairs to climb or descend from. The change of stair design could be the most optimal for an elderly population. If they are able to spend less energy climbing stairs, or ramps, then they could be able to spend more energy on other activities. Designing stairs in a more optimal way could make them safer for an older population to navigate.

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THE ADDITION OF OPTIC FLOW LESSENS AGE RELATED DIFFERENCES DURING GAIT ADAPTATION

Jessica Fujan-Hansen[1], Troy Rand[1] & Mukul Mukherjee[1]
[1]Department of Biomechanics, University of Nebraska at Omaha, Omaha, NE USA
email: jfujan@unomaha.edu

Presentation Preference: Poster

INTRODUCTION

Previous research in gait has shown that multiple components of locomotion in healthy populations differ when stratified by age. Examples include biomechanical variables such as step length [1], base of support, stance time, double support time [2], spatial and temporal parameters [3], as well as sensorimotor control [1]. While these studies indicate differences between healthy young and older populations, it is currently unclear at what age such decrements begin to have a significant impact. Furthermore, reviews have implied gait declinations in middle-age [4,5], however, assessments actually conducted on those between the ages of 40 and 59 are lacking. It is currently unclear if gait decrements from younger to older age follow a linear path. Specifically, the decrements in gait adaptation. Therefore, the purpose of this ongoing study is to determine the effect of age on gait adaptation in healthy participants.

METHODS

Preliminary data based upon 31 healthy individuals was broken down into young: n=10 (20 to 40 years of age); middle: n=10 (41 to 60 years of age); and older: n=11 (61 years of age and above) age groups. All participants performed a novel split-belt paradigm consisting of self-paced familiarization, baseline, early and late adaptation, stimulus removal, readaptation, and transfer trials on an instrumented dual-belt treadmill. The subjects were randomly assigned to complete the paradigm either within a Virtual Reality (VR) environment providing optic flow or within a static environment (nonVR).

Spatio-temporal parameters were calculated on each trial followed by symmetry calculations on each parameter for early learning (EL), late learning (LL), retention (RET), and overall learning (OL). Basic linear analysis was then performed between the three age groups, for VR and nonVR conditions.

RESULTS AND DISCUSSION

The preliminary results of this ongoing study revealed three items. First, all participants learned regardless of whether they completed the paradigm within the VR or nonVR environment. This was expected given the task requires walking adjustments in order to remain upon the treadmill surface. Second, significant group differences were found to exist within the nonVR condition for the temporal measure of stance time ($F=6.238$; $p=0.0140$) (Figure 1). This suggests the middle-age group employed a different strategy for timing foot placement during the gait cycle. Specifically, during LL and OL. This may signify that as middle-aged participants learn they make larger adjustments during the adaptation process due to perception of age-related alterations in gait. On the other hand, the older group has learned to respond to these age-related alterations in gait and therefore, exploration is lessened and their adaptation is closer aligned with the young. Finally, the significant group difference found for stance time during the nonVR condition dissipated when VR was added to the paradigm ($F=.257$; $p=0.777$) (Figure 2). This proposes that the addition of optic flow via VR removed the effect of age. As previously found, the addition of optic flow expedites adaptation [6]. This result suggests the addition of visually perceived motion helped aid in the timely response to age related gait alterations in learning a novel gait task.

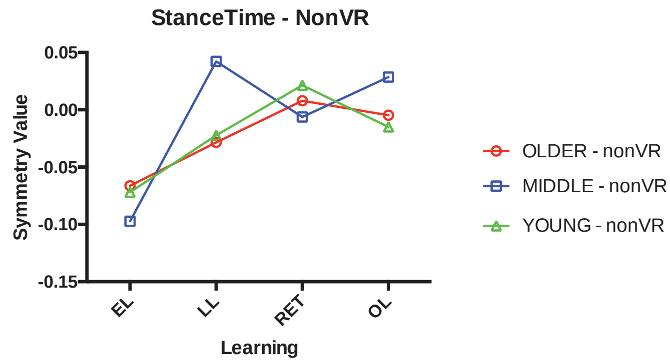

Figure 1: Symmetry values of stance time by learning stage for young, middle and older age groups within a nonVR environment.

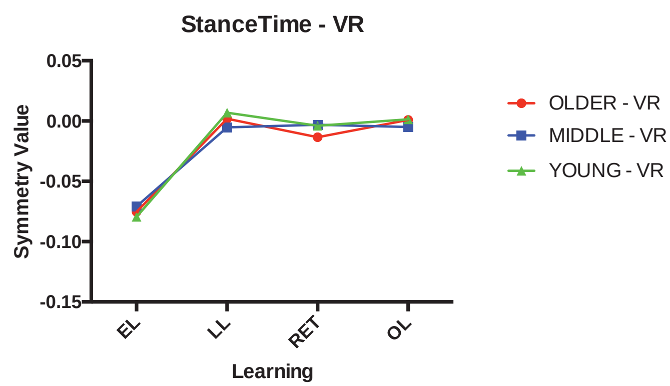

Figure 2: Symmetry values of stance time by learning stage for young, middle and older age groups within a VR environment.

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FREQUENCY-SPECIFIC FRACTAL ANALYSIS OF POSTURAL SWAY ACCOUNTS FOR POSTURAL CONTROL STRATEGIES

Pierre Gilfriche[1,2], Véronique Deschodt-Arsac[2], Antoine Kneblewski[2], Estelle Blons[2] & Laurent Arsac[2]
[1]Centre Aquitain des Technologies de l'Information et Electroniques, Talence, France
[2] Univ. Bordeaux, CNRS, IMS - Laboratoire de l'Intégration du Matériau au Système, UMR 5218, Talence, France
email: pierre.gilfriche@u-bordeaux.fr

Presentation Preference: [**Podium**]

INTRODUCTION

Diverse indicators of postural control in Humans have been explored for decades, mostly based on the trajectory of the center-of-pressure (CoP). Classical approaches focus on variability, based on the notion that if a posture is too variable, the subject is not stable. An improved understanding of the underlying physiology has then been gained from studying variability in different frequency ranges, pointing to specific short-loops (proprioception) and long-loops (visuovestibular) in neural control. More recently, fractal analyses have become useful additional metrics of postural control [1]. They have allowed authors to identify two scaling phenomena in postural control, respectively in short and long timescales [2].

METHODS

By designing and filtering a bank of synthetic fractal signals, we established that scaling analysis can be focused on specific frequency components in Detrended Fluctuation Analysis (DFA), by matching box size to frequency component. We obtained the relation $n=f/f_s$ (with n the box size, f the equivalent frequency, f_s the sampling frequency) which allowed to focus scaling analysis in DFA, a method we called Frequency-specific Fractal Analysis (FsFA).

The method can be applied to analyze scalings in postural control on frequencies associated to proprioceptive-based control and visuovestibular-based control. CoP position and CoP velocity were analyzed this way on the antero-posterior axis. We tested the method in an exploratory study on 8 female rugby players (age 20.3±1.1 years, mass 63.2±6.5kg, height 164.3±6.4cm) whose CoP signals were recorded at 40Hz for 51.2s. Participants repeated the measure in three situations i) rested with eyes open (*reference*) ii) rested with eyes closed (*eyes closed*) iii) fatigued with eyes open (*fatigue*). Physical fatigue was induced with intense exercise.

RESULTS AND DISCUSSION

The analysis shows that the two scaling phenomena observed in the literature [2] are localized on the frequency-ranges associated with proprioceptive-based and visuovestibular-based postural control.

Using the obtained Frequency-specific scaling exponents (Fs-α), results reveal the presence of 1/f noise in velocity in short time-scales and in position in long time scales (Table 1). By interpreting such behavior to a loosely controlled variable, this suggests that at least two timescales contribute to postural control: a velocity-based control in short timescales relying on proprioceptive sensors, and a position-based control in longer timescales with visuovestibular sensors. These two complementary control loops would ensure both a fast velocity-based control and a slower drift-correcting control. We think the best explanation for the apparition of both scalings is that the two neural networks responsible for control loops self-organize the distribution of control delays to a power law [3].

This organization of delays is likely an indicator of control strategies. It was evidenced by changes in CoP velocity short scale Fs-α and CoP position large scale Fs-α when altering system input (eyes closed or fatigue) as shown in Figure 1.

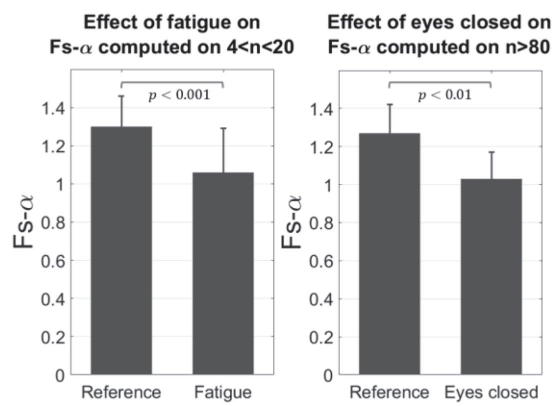

Figure 1: Effect of control loop alterations on frequency-specific fractal exponents.

CONCLUSIONS

Frequency-specific scaling exponents open new ways to understand the physiology of postural control and are promising markers of control strategies in Humans.

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Table 1: Frequency-specific fractal exponents of CoP position and velocity of subjects in the reference state.

Fs-α		
	on CoP position	**on CoP velocity**
on proprioceptive loop (4 < n < 20)	1.93 ± 0.04	1.30 ± 0.16
on visuovestibular loop (n > 80)	1.27 ± 0.15	0.39 ± 0.10

DEVELOPING A FOOTSWITCH DEVICE TO ASSESS THE LIKELIHOOD OF FALLS IN AT-RISK POPULATIONS

Arash M. Gonabadi[1], Prokopios Antonellis[1], Travis Vanderheyden[1], Karina I. Bishop[2] & Philippe Malcolm[1]
[1] Department of Biomechanics and Center for Research in Human Movement Variability, University of Nebraska at Omaha, Omaha, NE, USA
[2] Department of Internal Medicine, University of Nebraska Medical Center, Omaha, NE USA
email: amgonabadi@unomaha.edu, web: http://coe.unomaha.edu/brb

INTRODUCTION

Falls are an important and pressing issue for our aging population due to the societal and economic costs associated with these adverse events. Unexpectedly, coming to rest at a lower level is defined as fall, which may lead to mortality amongst the elderly [1]. One third of older adults over the age of 65 years, experience at least a fall every year [2]. Most of the falls occur during walking and therefore, it is important to find a relationship between the walking performance and falls. A component of walking mechanics that has been associated with falling in the elderly is gait variability (i.e. the inherent natural fluctuations between strides). Gait variability is shown when stride-to-stride fluctuations are examined over long-time series. Nonlinear analysis methods can provide insight about the underlying control system affecting gait variability [3]. Healthy states are associated with an optimal level of movement variability, which reflects the adaptability of the underlying control system [4]. Pathological gait, on the other hand, can be either too regular, or periodic, or too random and disordered [5]. Our objective is to develop a footswitch device including a programmed microprocessor electronic board and insoles with pressure sensors to measure gait variability and evaluate fall risk in at-risk populations (e.g. the elderly).

METHODS

We are recruiting twenty healthy older adults and ten older adults who have experienced a fall. We will ask participants to perform three clinical functional tests: 1) The timed up and go test. This test involves sitting in a chair, standing up from a chair and walking to a piece of tape 3 meters away, turning around, walking back to the chair, and sitting back down. We will give participants a practice trial of this test before it is timed. 2) The Berg Balance scale test. This test involves different tasks such as sitting, standing, weight transfers and reaching under different support and visual conditions. 3) The dynamic gait index test. This test involves different tasks such as sitting, standing, weight transfers and reaching under different support and visual conditions. Finally, we will ask participants to walk on a treadmill for 10 minutes at 0.8 $m.s^{-1}$ with foot switch prototype (gait-o-gram). We will place the footswitch device on the participant's heels and toes to capture the temporal parameters of gait as they walk on the treadmill (Fig. 1). We will extract the stride interval time series from the footswitch data and apply two nonlinear analysis methods (Coefficient of Variation and Detrended Fluctuation Analysis) to assess gait variability between healthy older adults and older adults who experienced a fall (Table 1).

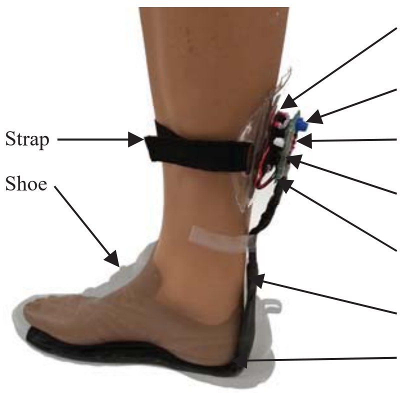

Figure 1: Footswitch device with the insole and sensors

Table 1: Comparison of measurements with footswitch to gold standard (Bertec treadmill). Results are from one participant.

	Bertec	Footswitch
Mean stride time (s)	1.12	1.12
Coefficient of variation	0.02	0.03
DFA scaling coefficient	0.82	0.69

ANTICIPATED RESULTS AND DISCUSSION

We expect to find an association between the results obtained from the footswitch device and the clinical functional tests that can illuminate the way to determine the risk of falling with more accurate and inexpensive gait assessments. This research will provide the basis for moving gait analysis out of otherwise immobile (and expensive) clinical laboratories to a portable system.

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Effects of Foot Temperature Increase on Skin Sensitivity and Balance

Angel E. Gonzalez [1], Andrew M. Kern[1], Kota Z. Takahashi[1]
[1]Department of Biomechanics, University of Nebraska at Omaha, Omaha, NE USA
email: agonzalez@unomaha.edu, web: https://www.unomaha.edu/college-of-education/cobre/

Presentation Preference: [**Poster**]

INTRODUCTION

Foot temperature regulation is a crucial aspect of maintaining structural integrity of the foot (i.e. tissue structure optimized for load bearing) and decreasing foot complications such as ulcer formation [1,2]. Foot temperature may have an influence on skin sensitivity and postural balance that lead to a decrease of plantar foot structural integrity. Previous studies have demonstrated that foot cooling to near freezing conditions has an adverse effect on skin sensitivity and balance [3,4]. Likewise, skin sensitivity and balance of the foot may also decline due to an increase in temperature. It is currently unclear how temperature increase affects skin sensitivity and postural balance. Producing a detailed temperature profile of the foot can provide solutions to keep the foot cool during and after activity and thus provide an increase in structural integrity of the heel pad, skin sensitivity and postural sway variation.

The purpose of this study is provide insight into the effects of prolonged walking on foot temperature during activity as well as during recovery. This study can provide an understanding of the possible interaction between foot temperature, skin sensitivity and postural balance. As other studies have previously shown [2,5], it is expected that temperature will increase linearly and reach a plateau after reaching 15 minutes (Fig. 1). Moreover, foot temperature is expected to have a fluctuation range of ~5 degree Celsius from the subject's baseline values [2,6]. During prolonged walking, we hypothesize that an increase in foot temperature will be correlated to a decrease in skin sensitivity and decreased postural balance. During recovery, we hypothesize that a decrease in foot temperature will be correlated with an increase in skin sensitivity and an improvement in postural balance.

METHODS

This study will measure foot temperature, skin sensitivity and balance on three randomized testing day trials: treadmill walking, external heating and a control visit. The study will consist of 16 healthy individuals. To assess the mechanical effect of foot temperature-change on skin sensitivity and balance, the first visit will consist of the participant walking on a treadmill at 1.25 m/s for a prolonged period of 30 minutes. Baseline temperature, postural balance, and skin sensitivity will be measured on all trials in interval recordings (6 min.). Temperature changes and skin sensitivity will be recorded at six sites within the right foot (heel pad, under and above the 1st metatarsal head, under the hallux, under and above the 5th metatarsal head) and four additional sites (tibialis anterior, gastrocnemius, hamstring, quadriceps) of the right leg. Temperature values will be measured using an infrared thermal camera (FLIR T540sc, FLIR Systems Wilsonville, OR). Skin sensitivity will be measured with a Biothesiometer using a vibration frequency method [7]. The subject's postural balance will be measured using a force plate set at 1000 Hz with closed eyes while in a one-legged stance and analyzed using the root-mean square method of the displacement of the center-of-pressure. The second visit will isolate the effect of foot temperature without the influence of mechanical loading encountered during walking. This will be achieved by heating the foot with a heating pad for 30 minutes with six-minute intervals. To analyze whether a practice effect occurs across multiple testing, a third visit will involve the participant standing on a force sensing platform for six trials on the right leg with six-minute interval measurements. The subject's balance will be compared in between each of these subsequent days by comparing time points across each value.

RESULTS AND DISCUSSION

Data is currently in the process of being collected. If the first hypothesis is supported, it may indicate foot cooling methods need to be created to support the structural integrity of the foot, particularly in neuropathic populations who are prone to falling, due to decreased skin sensitivity and postural balance. If the second hypothesis is supported, this may indicate that structural integrity of the foot is maintained by temperature regulation.

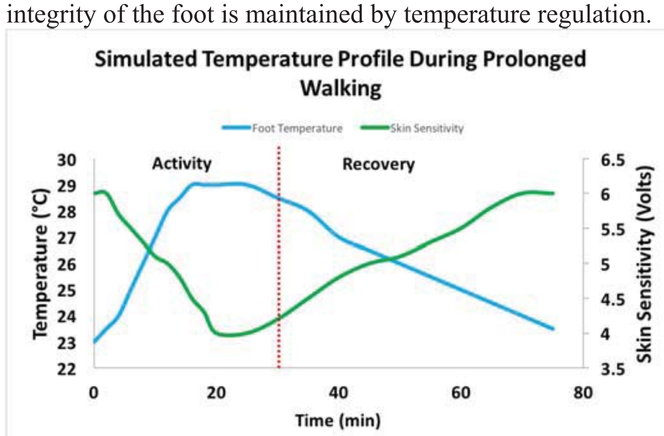

Figure 1: Simulated temperature profile of the foot during prolonged walking in activity and recovery.

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Examining the minute to minute predictability of walking distance across multiple terrains

Tyler Hamer, Abderrahman Ouattas, Katlyn Nimtz, Brian A. Knarr
Department of Biomechanics, University of Nebraska at Omaha, Omaha, NE USA
Email: thamer@unomaha.edu, Web: https://www.unomaha.edu/college-of-education/cobre/

Presenter Preference: Poster

INTRODUCTION

The 6-minute walk test (6MWT) is useful for longitudinal assessment as well as monitoring treatment response and is considered a simple method for assessing exercise capacity at a submaximal level[1]. In recent years, we have begun to shorten the duration of clinical walking tests as correlations between duration of the test and findings become more apparent[2]. With findings that the 6MWT is more efficient than the original 12-minute walk test (12MWT), perhaps it can be evident that even the 6MWT can be shortened to examine its effects in a shorter duration that can be more beneficial to the participant. The objective of this study is to examine the outcomes of each minute throughout the 6MWT trials and to see if functional measures can be obtained at an early mark to facilitate the effects of movement variability throughout the trial. We hypothesize that there are strong correlations between walking distances during the first three minutes to distances in the last three minutes of the test. Additionally, we hypothesize that individuals who walk farther will have less minute to minute variability.

METHODS

Table 1: Subject Information

	Mean (SD)
Age	65.1 (10.1)
Mass (kg)	74.8 (17.7)
Height (m)	1.6 (.1)
BMI	27.7 (6.3)

Subjects included in this study were healthy adults between the age of 40 and 85 years old. Exclusion criteria pertained to those who have self-reported maximal joint pain >3/10 of the hip, knee, or foot as well as if they had doctor-diagnosed hip or knee osteoarthritis. Having already been diagnosed with a neurological disorder including stroke, traumatic brain injury, or any other neurological condition that affects their decision-making or ability to move normally excluded them from the study as well. A total of 18 healthy older adults participated within this study. Age, height, weight, and BMI were recorded for each individual (Table 1). Subjects completed three walking trials on the same day on three different surfaces: an indoor track, an outdoor paved surface, and an outdoor unpaved surface. Subjects were first asked to cover as much distance as possible on an indoor track during a six minute span. Upon completion, a short break was given and subjects proceeded outside onto a nearby circular sidewalk path outside of the research building. The sidewalk path was chosen to preclude any stepping or turning patterns not typical of a standard 6MWT. Subjects were then instructed to walk as far as possible on this surface within a three-minute span of time. Lastly, subjects conducted the same three minute walk test directly off from the sidewalk surface on the grass. To maintain consistency between subjects for the grass surface, collections did not take place within 24 hours of heavy precipitation, and an examination of the surface was made prior to data collection. Throughout all trials, the total distance walked was measured using a rolling measuring wheel alongside the participant. Distances were collected at every minute mark. Linear regressions were performed to measure predictability of data from minute to minute. R^2 values were recorded to signify predictive trends amongst each minute within the trials.

RESULTS AND DISCUSSION

Linear regressions revealed that distance within the first few minutes significantly predicted performance around the six-minute mark. Results indicated that very strong correlations between the mean distances walked across minutes appeared around the two-minute mark, with an R^2 value of .95. This shows that the first minute is unreliable of 6 minute findings yet by the second minute, you can highly predict results that you would find at the end of the 6MWT. Ultimately, with other studies working with the 2-minute walk test (2MWT)[3,4], researchers have shown it is possible replicate 6MWT findings in shorter durations. Shortening these functional tests can help patients who struggle with various walking deficiencies as well as shortening exam research protocol altogether. When observing between total distance walked and the minute-to-minute variability in distance amongst participants, it was found that no correlation between the two variables exists.

Table 2: Minute to minute correlations of distance walked.

	1 v. 3	2 v. 3	1 v. 6	2 v. 6	3 v. 6	4 v. 6	5 v. 6
Track	.69	.96	.64	.95	.98	.99	.99
Paved	.59	.99	-	-	-	-	-
Unpaved	.90	.96	-	-	-	-	-

CONCLUSION

We hypothesized that correlations would be found between the first few minutes of a 6MWT to that of the end of the trial. R^2 values started to show highly predictive values around the two minute mark and continue to strongly correlate with each passing minute. While these findings prove highly relevant for healthy populations, further research needs to be conducted to elaborate on shortening the 6MWT in consideration to injured populations. Additionally, future investigation into possible is changes in kinematics from minute to minute is planned.

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HOW PROSTHETIC ANKLE STIFFNESS & LOAD CARRIAGE AFFECT METABOLIC ENERGY EXPENDITURE DURING WALKING

Erica A. Hedrick[1], Philippe Malcolm[1], & Kota Z. Takahashi[1]
[1]Department of Biomechanics, University of Nebraska at Omaha, Omaha, NE USA
email: ehedrick@unomaha.edu, web: https://www.unomaha.edu/college-of-education/cobre/

Presentation Preference: **Poster**

INTRODUCTION

Individuals with transtibial amputation typically consume more metabolic energy (up to 25% more) during walking than individuals without amputation [1]. This added energy cost could be, in part, due to altered gait to compensate for the absence of muscles distal to the amputation, such as the ankle plantar flexor muscles that provide a majority of lower extremity power production during push-off [2]. Muscles proximal to the amputation have to make up for the work usually done by the absent muscles [2].

Another factor that will affect the metabolic cost and gait of an individual with an amputation is their prosthetic ankle stiffness [3]. It is currently unclear how prosthetic ankle stiffness should be prescribed for individuals walking under varying levels of added loads. Ankle stiffness, or resistance to angular motion, can directly affect the amount of mechanical energy that is stored and returned [4]. One limitation of most unpowered (i.e., elastic) prosthesis is that the ankle stiffness cannot be readily manipulated during use, which may hinder the individuals' ability to adapt to walking under various mechanical demands, such as walking with added loads. In contrast, the typical human ankle can adjust its stiffness due to active muscle contractions [5].

The purpose of this study is to examine the effects of prosthesis ankle stiffness and carrying additional loads on the net metabolic cost of walking. As a proof of concept, this study will involve individuals with a simulated amputation by using an immobilizer boot with the prosthesis.

METHODS

Participants will simulate amputation by wearing a prosthesis with an immobilizer boot attached. An experimental ankle-foot prosthesis emulator (HuMoTech, Pittsburgh, PA) will be used to systematically vary ankle joint stiffness [6], effectively simulating a prosthesis with a range of different elasticities and compliances.

This experiment will consist of nine conditions. The nine conditions will include three different prosthetic stiffness settings (low, medium and high stiffness) and three different load carrying conditions via a weight vest (no added mass, 15%, and 30% added body mass). The low stiffness condition will correspond with the stiffness of the normal human ankle [7] and the medium and high conditions will incrementally increase. Order of the conditions will be randomized to account for the potential effect of learning or habituation. For each condition, the subject will walk for six minutes at a speed of 1.25 m/s. Breath-by-breath gas exchange measurements will be recorded for indirect calorimetry calculations of metabolic cost (True One, Parvo Medics). Three-dimensional limb and joint motion will be captured using an eight-camera motion capture system (VICON, Oxford, UK), as subjects walk on a force-sensing treadmill (Bertec, Columbus, OH). A rest period of at least five minutes will occur between each condition to allow for recovery and to minimize fatigue.

RESULTS AND DISCUSSION

No data has been collected thus far, but this study has three hypotheses (see Figure 1): (1) A lower prosthetic stiffness will decrease the net metabolic cost of walking (with no added load); (2) An addition of load will increase the net metabolic cost of walking; (3) The effect of stiffness on metabolic cost will vary as a function of load carriage. If these hypotheses are supported, the results from this experiment can aid in prescribing both powered and unpowered prosthesis. If there is an interaction effect between stiffness and load carriage, then a powered prosthesis can be programmed to vary the stiffness when additional load is applied. In unpowered prosthesis, a nonlinear spring that changes stiffness like how the human ankle changes during unloaded and loaded conditions may be used to decrease the metabolic cost for individuals with an amputation.

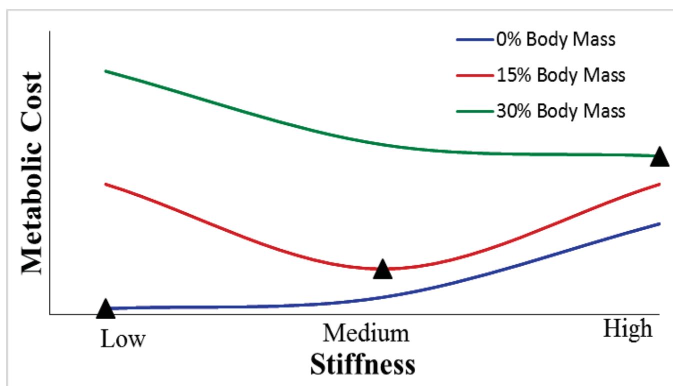

Figure 1. Hypothesized metabolic cost of walking at 0% (blue), 15% (red), & 30% (green) additional load for each stiffness.

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EFFECT OF THE USAGE OF HANDRAILS ON GAIT DYNAMICS IN PEOPLE WITH PARKINSON'S DISEASE

Daniel Jaravata[1], Vivien Marmelat[1], & Danish Bhatti[2]
[1]Department of Biomechanics, University of Nebraska at Omaha, Omaha, NE USA
[2]Department of Neurological Sciences, University of Nebraska Medical Center, Omaha, NE USA
email: djaravata@unomaha.edu, web: https://www.unomaha.edu/college-of-education/biomechanics-core-facility/index.php

Presentation Preference: **Poster**

INTRODUCTION

In young, healthy adults, stride time-series of walking presents a complex pattern of fractal fluctuations characterized by scale invariance, i.e. where deviations appear the same at different observations scales (from a few seconds to a few hours). Fractal fluctuations characterize an optimal state of complexity, between too much regularity (periodicity) and too much irregularity (randomness). This can potentially allow the locomotor system to maintain robust performances while being able to adapt to perturbations such as uneven terrain or obstacle avoidance. However, fractal fluctuations in stride time-series of patients with Parkinson's disease (PD) are altered more towards randomness [1,2]. The consequences of decreased complexity in patients with PD aren't fully understood, but deviations from complex variability have been associated with risk of falls [3-5].

A possible explanation is that the decrease in complex variability results from increased control mechanisms to avoid excessive postural instability (e.g. center of mass deviations), which is already impaired in patients with PD [6]. While treadmill walking using handrails is widely used in gait rehabilitation, its impact on gait variability is not fully understood. Previous research has shown that healthy young subjects walking on a treadmill while grasping handrails increased the complexity of stride time-series compared to normal treadmill or over-ground walking [7].

The purpose of this project is to determine the effect of handrails-use while walking on a treadmill on gait variability in patients with PD.

METHODS

Fifteen PD patients (ages 60 and above), fifteen age-matched controls, and fifteen healthy young adults (ages 15-35) will be recruited. Eligible participants will complete a series of questionnaires and clinical tests including Hoehn & Yahr scale, Timed Up and Go, Fullerton Advanced Balance scale, Modified Fall Efficacy Scale, Montreal Cognitive Assessment, the Geriatric Depression Scale and the Freezing of Gait Questionnaire.

Figure 1: Representative example of a participant walking while holding the handrails.

Participants will complete one data collection consisting of two fifteen-minute walking trials on a treadmill will wearing a safety harness. Kinematics data will be collected through the use of motion-capture cameras (120Hz) recording reflective markers on subjects' anatomical landmarks. All participants will complete two walking conditions at a self-selected preferred walking speed. One condition will entail the participants walking on the treadmill without any external assistance. The other condition will consist of participants walking on the treadmill while stabilizing themselves by holding the handrails at the side of the treadmill. Participants will be provided at least five minutes of rest between the two conditions, more if necessary, and the order of conditions will be randomized.

The main outcomes will be center of mass (COM) deviations in the medial-lateral direction, reflecting overall body stability, and the complexity of stride-to-stride fluctuations (stride time and stride length). Analysis of the stride-to-stride fluctuations will be conducted using detrended fluctuations analysis (DFA), which provides a scaling exponent alpha-DFA reflecting the level of complexity (i.e. fractal fluctuations are characterized by alpha-DFA=1, while random fluctuations correspond to alpha-DFA=0.5).

Two-way (3 groups x 2 conditions) repeated measures ANOVAs will be used to determine differences in outcome variables, using a significance threshold of $p<0.05$. In addition, Pearson's coefficients of correlation between medial-lateral COM deviations and alpha-DFA values will be used to determine the relationship between global body stability and stride-to-stride fluctuations.

EXPECTED RESULTS & DISCUSSION

We hypothesize that walking on a treadmill while grasping handrails will increase the complexity of gait variability in patients with PD and be associated with reduced postural instability (reduced COM deviations), reflecting the tight relationship between gait complexity and motor stability. Our results may impact gait rehabilitation, where handrails are typically used.

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Protoyping and Fabrication of a Variable Surface Treadmill

Nick Jaton[1], Travis Vanderheyden[2] & Kota Takahashi[2]
[1]Department of Electrical & Computer Engineering, University of Nebraska at Lincoln, Lincoln, NE USA
[2]Department of Biomechanics, University of Nebraska at Omaha, Omaha, NE USA
email: njaton@unomaha.edu
Presentation Preference: [**Poster**]

INTRODUCTION

Upon returning from missions, astronauts often lose muscle mass that is necessary for maintaining healthy gait movement [1]. The variable surface treadmill will allows for a better understanding of the effects of returning from orbit and how to help decrease the time that is needed in physical therapy. This device is able to generate a surface that uses small movable structures that ultimately creates a random surface or replicates a surface that already exists. This treadmill is to be created utilizing 3D printing technology to decrease cost and allow for easy customization.

METHODS

The development of the treadmill was started by creating one individual "cell" or structure. The cell consists of a m5 bolt that is connected to a small motor via a custom 3D printed coupler. The outside casing and the coupler are both made out of polylactic acid based material (PLA). The 3D printing lab located in the Biomechanics Research Building was utilized during this design process. We utilized Autodesk's Fusion 360 software to draft up the mechanical components of the treadmill.

In order to test the operation of the mechanical parts created for the treadmill both an Arduino UNO and an Arduino Mega were used. The Arduino was then connected to a TB6612 motor controller to allow for both forward and backward movements of each motor. The Arduino programming application was used to create the looping structures to control each cell. The language utilized in this software uses a subset of C/C++ functions that you are able to call through your program[2]. Three buttons were added to the circuit. The first button is used to generate a random number to decide the distance for each cell. The second button will move the bolt upwards to the desired location. The third and last button is used to bring the cell back to the home location.

RESULTS AND DISCUSSION

Currently a proof of concept has been created. This proof has three different cells that demonstrate the function of a row of cells and the methods that will be used to create them. After some design modifications the proof of concept was made to work as expected. [Figure 1]. The treadmill will eventually be made of more than one thousand of these individual cells controlled by an ATmega2560 microcontroller for each row. Currently research has been focused on a printed circuit board (PCB) design that will be used to control a small matrix of the previously mentioned cells. A locking top is also being designed to be able to support to weight of the individual using the treadmill.

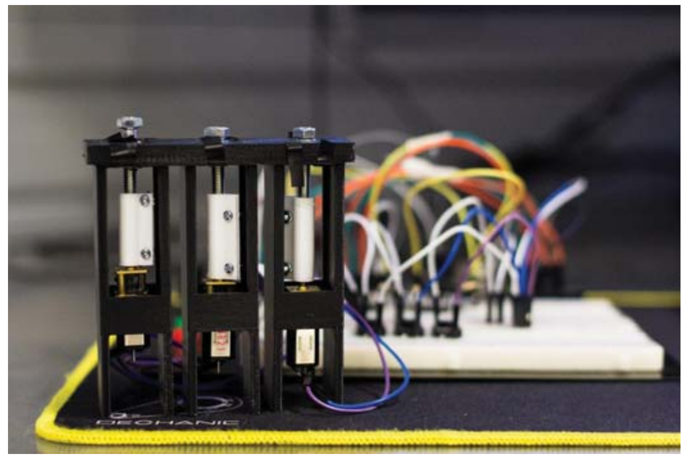

Figure 1: Image showing the proof of concept build that was utilized in testing and design. Three of the 3D printed cells are shown in the image. The cells are connected to the control circuit that was created on a breadboard.

CONCLUSIONS

In order to help assist astronauts upon their return from future mission the concept of a variable surface treadmill was created. This project combines the study of mechatronics and biomechanics in order to create a new valuable tool for rehabilitation. The focus on 3D printing will allow for easy and cost effective repairs for the users as well as allowing for low cost customization.

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STABILITY MARGINS ARE ALTERED ON UNEVEN TERRAIN IN INDIVIDUALS WITH A UNILATERAL TRANSTIBIAL AMPUTATION

Jenny Kent[1], Kota Takahashi[1] & Nicholas Stergiou[1,2]
[1]Department of Biomechanics, University of Nebraska at Omaha, Omaha, NE USA
[2]College of Public Health, University of Nebraska Medical Center, Omaha, NE USA
email: jkent@unomaha.edu, web: https://www.unomaha.edu/college-of-education/cobre/

Presentation Preference: Podium

INTRODUCTION

Walking on uneven terrain is a known challenge for people with a lower limb amputation, and a barrier to mobility and participation [1]. Safe and efficient ambulation requires the ability to effectively control the center of mass (COM) of the body with respect to the base of support provided by the feet [2]. The lack of sensation and active control of a natural foot may reduce the ability of the individual to sense and appropriately react to inconsistencies in terrain. As such, it might be anticipated that COM control above the foot will be suboptimal, leading to more instances of potential imbalance, and the increased likelihood of a fall. Previous studies exploring short traverses of inconsistent terrain have shown increases in variability in the medial-lateral step dynamics of lower limb amputees, although no increases in stability margins (i.e. the average relationship between COM and the boundary of the base of support neither increased nor decreased) (e.g. [3]). It is possible that longer stretches of terrain may yield different results given a greater distance to walk with no opportunity for recovery. The aim of this work was to explore the dynamic balance of individuals with a transtibial amputation walking on continuous uneven terrain. It was hypothesized that there would be greater unsteadiness on uneven terrain, evident in a higher variability of stability margins, and that margins on average would be increased as an active means of reducing sideways fall risk. Further we anticipated that these dynamics would change with familiarization; specifically, that variability would reduce with practice, and stability margins would decrease, consistent with an increase in confidence.

METHODS

Eleven experienced prosthesis users with a transtibial amputation (8M 3F; 56.6±12.6 yrs; 101.9±16.4 kg; 1.79±0.07 m) walked on two treadmills: flat (FL; Tandem Treadmill, AMTI Inc, MA) and uneven terrain (UT; in-house built) at their preferred UT treadmill speed (1.0±0.2 m/s) for two minutes each. Participants were asked to walk without using handrails if confident to do so, or to maintain a light touch if not. Kinematic data were recorded using a 12-camera motion capture system (Motion Analysis Corp., CA). COM position and velocity, and lateral foot position were estimated based on marker data for 60 consecutive strides in each walking condition. Bilateral medial-lateral margin of stability [2] (MOS_{ML}) and its variability (standard deviation; $vMOS_{ML}$) were computed in Visual 3D (C-Motion Inc, MD).

The two variables were first examined using 2 X 2 repeated measures ANOVAs with within subjects factors of limb (sound, prosthetic) and condition (FL, UT). Strides 1-10 and 50-60 were then compared using paired t-tests. Finally, due to differences in hand position and cohort heterogeneity, post-hoc analysis was additionally performed on single subject MOS_{ML} data using the Model Statistic [4].

RESULTS AND DISCUSSION

8 of 11 participants chose to walk with their hands on the handrails on UT. Inconsistent with previous studies, MOS_{ML} was higher on UT on the prosthetic side (Figure 1; p=0.041). As anticipated, $vMOS_{ML}$ was higher on UT (p<0.001). Corroborating our grouped data, individual analysis revealed that 8 participants had a significantly higher MOS_{ML} on the prosthetic side on UT, regardless of hand position, however results were less consistent across participants on the sound side, potentially indicating differences in strategy. No significant differences were observed across time, however a decrease in prosthetic side MOS_{ML} approached significance (p=0.0595). 3/11 individuals significantly decreased their prosthetic side MOS_{ML}, however this was on both FL and UT. Analysis of longer duration bouts of walking may determine whether benefits to balance may be obtained by practice on UT.

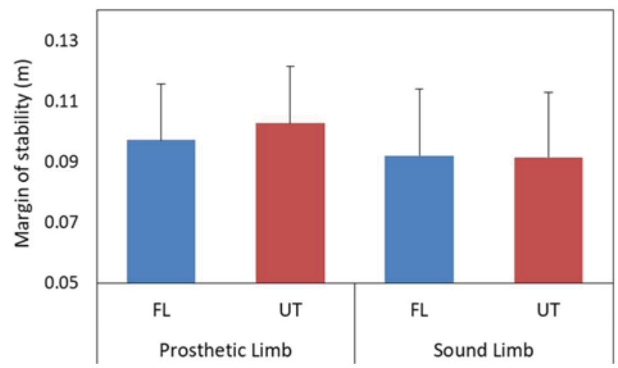

Figure 1: Medial-lateral margin of stability on flat (FL) vs uneven (UT) terrain; mean of 60 strides (*sig at p=0.05).

CONCLUSIONS

As hypothesized, UT affected stability margins and their variability in transtibial amputees. Increasing MOS_{ML} on the prosthetic side may be a mechanism to prevent a sideways fall. Our findings suggest some familiarization may have occurred in a few individuals over only 50 strides.

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WALKING WITH ADDED MASS INFLUENCES ANKLE AND MID-TARSAL JOINT QUASI-STIFFNESS

Andrew M. Kern[1], Nikolaos Papachatzis[1], Jeffrey Patterson[1], Dustin Bruening[2] & Kota Z. Takahashi[1]
[1]Department of Biomechanics, University of Nebraska at Omaha, Omaha, NE USA
[2]Exercise Science Department, Brigham Young University, Provo, UT USA
email: andrewkern@unomaha.edu, web: https://www.unomaha.edu/college-of-education/cobre/

Presentation Preference: **[Poster]**

INTRODUCTION

Mechanical behavior of the human foot is a complex interplay of joints and soft tissues that allow for adaptation to a wide range of environments and gait strategies. Quasi-stiffness (also called dynamic stiffness [1]), the ratio of the external joint moment and angle, [2] is a property which characterizes the dynamic behavior of joints during locomotion. A deeper understanding how the foot and ankle modulate quasi-stiffness across a wide range of locomotor activities may have implications for treatment of gait pathology, improvement of human performance, and design of assistive devices. Preliminary investigations have characterized quasi-stiffness of the human ankle, mid-tarsal and metatarsal phalangeal joints in walking and running [1,2]. The effect of added body mass on quasi-stiffness during walking has not yet been quantified and is particularly important for the design of augmentative or assistive devices (e.g., prostheses, exoskeletons, shoes).

This study seeks to understand the quasi-stiffness of the human ankle and mid-tarsal joints during over-ground walking with additional body mass. Based on previous literature findings, it is hypothesized that ankle and mid-tarsal joint quasi-stiffness will increase when walking with greater levels of added mass.

METHODS

Gait analysis was performed on 18 healthy subjects (age = 24.6 ± 2.8 years, height = 1.75 ± 0.06 m, mass = 85.3 ± 21.1 kg), while wearing three levels of weighted vest, 0%, 15% and 30% additional body mass. Prior to data collection, subjects were instrumented with a set of 53 retro-reflective markers, allowing for motion analysis of the hips, knees, ankles and a multi-segment foot model [3]. All subjects were tested walking over-ground (at 1.25 m/s) with the three levels of mass, in randomized order within a single day data collection.

Kinematic and force-plate data were processed in Visual3D (C-Motion, Germantown, MD) to determine joint angles and moments in the ankle, and mid-tarsal joints . Further processing was completed within a custom MATLAB (Mathworks, Natick, MA) script, which computed joint quasi-stiffness for two phases within gait. These phases form two predominantly linear regions of the moment-angle curve for both ankle and mid-tarsal joints [2]. The dorsiflexion phase (DF) corresponds to ankle dorsiflexion during mid-stance, and the plantarflexion phase (PF) corresponds to ankle plantar flexion during late-stance [2]. Joint quasi-stiffness is quantified as the slope of a linear fit to the moment-angle curve within that phase.

RESULTS AND DISCUSSION

A one-way repeated measures ANOVA determined that quasi-stiffness increased significantly ($p<0.001$) with added mass in the ankle for DF and PF phases and in the mid-tarsal joint for PF (Figure 1). No statistical significance was found in the mid-tarsal joint during DF ($p = 0.225$). Post-hoc tests revealed that a 30% increase in body mass correlated with a significant increase in stiffness (from 0%) across all joints, however no significant increase was found from 15% to 30% in the mid-tarsal joint during PF.

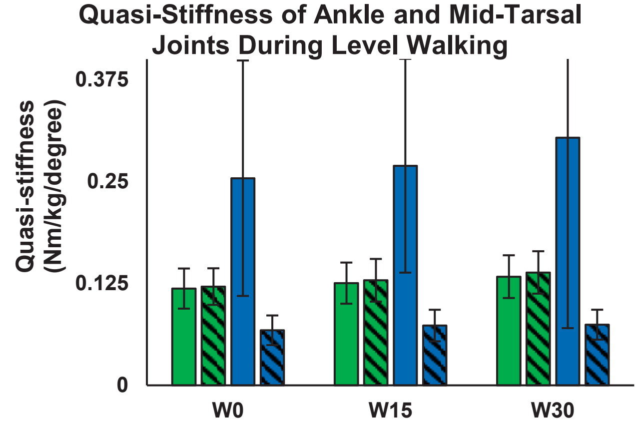

Figure 1: Quasi-stiffness of the ankle (green) and mid-tarsal (blue) joints during DF (solid) and PF (striped) phases. For a given level of mass carriage (W0, W15, and W30), ankle quasi-stiffness is similar between both phases, whereas mid-tarsal joint stiffness is substantially decreased.

These results support the hypothesis that ankle stiffness increases with added body mass, however an increase in mid-tarsal joint stiffness was only partially supported (no significant increase in DF). Interestingly, the mid-tarsal quasi-stiffness displayed a distinct difference in behavior between DF and PF phases with high variability between subjects, whereas the ankle joint was more uniform. This finding may be due to difficulties of measuring mid-tarsal joint motion, or differences in subject arch height, soft-tissue or muscle activation patterns.

CONCLUSIONS

The quasi-stiffness of the ankle during stance mid-tarsal joint during push-off increases with increase body mass. These findings inform how wearable devices may be tuned to accommodate variable walking and loading conditions.

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THE EFFECT OF FATIGUE ON JUMPING PERFORMANCE AND BIOMECHANICS

Eric N. Knight[1], Chelsea Klemetson[1], Brooke Farmer[1], Dimitrios Katsavelis[2], & Terry L. Grindstaff[1]
[1]Department of Physical Therapy, Creighton University, Omaha, NE USA
[2]Department of Exercise Science and Pre-Health Professions, Creighton University, Omaha, NE USA
email: grindstafftl@gmail.com, web: https://spahp.creighton.edu/research/rehabilitation-sciences-research-laboratory

Presentation Preference: [**Poster**]

INTRODUCTION

Non-contact anterior cruciate ligament (ACL) injuries are a devastating sports injury that have increased injury rates near the end of competition [1,2,3]. The utilization of functional performance tests is important for return to sport decisions for athletes following injury. Functional performance tests, such as the single leg forward hop test [4], are often performed in non-fatigued conditions, despite increased injury rates in fatigued states near the end of competition [1,2,3]. Previous studies have indicated mixed effects on lower extremity biomechanics, motor control, and coordination due to fatigue, potentially increasing risk for an ACL injury [5, 6]. However, the exact role of fatigue on lower extremity biomechanics during functional tests is not fully understood.

More recent functional performance tests such as the chair to box test, lateral hurdle hop test, and the 30-second side hop test may also be useful in the battery of test for determining return to sport. Utilizing a multitude of simple tests that can be performed with minimum equipment, such as those previously listed, is beneficial as many clinics do not have a surplus of equipment to use. However, these tests have limited research supporting their use with athletes with a history of ACL reconstruction (ACL-R).

The primary purpose of this study was to determine the effects of a fatigue protocol on jumping performance and lower extremity biomechanics in individuals with and without a history of ACL-R. The secondary purpose of this study was to determine the between session reliability for the 30-second side hop, lateral hurdle hop, and chair to box task.

METHODS

This study is cross-sectional in design. Participants will include individuals with a history of ACL-R in past 3-24 months and a matched healthy control. Prior to data collection, subjects will complete patient reported outcome forms including the IKDC, KOOS, and ACL-RSI. Participants will jog for five minutes at a self-selected pace on a treadmill for a warm up before testing begins. Quadriceps strength will be measured using an isokinetic dynamometer (Biodex). Dominant limb, classified as the limb used to jump off for maximal height, or uninvolved limb will be tested first for all tests followed by the non-dominant/involved limb. Jump testing will include the chair to box task, lateral hurdle hop, forward hop, 30 second side hop, 2-minute lateral step down, and fatigued forward hop. Retroreflective markers will be placed along anatomical landmarks using double sided tape and motion capture data will be collected using Qualisys paired with over ground embedded Bertec force plates. Subjects will report to the lab for a follow-up visit 3-7 days later and will repeat the same jump testing protocol to determine between session reliability.

RESULTS AND DISCUSSION

This study is currently undergoing data collection, statistical analysis has not yet been completed. Subjects are presently being recruited to participate in this study.

CONCLUSIONS

We hypothesize fatigue will have an impact on jumping performance and also influence biomechanical changes in the lower extremities during jumping tasks. Biomechanical changes we hypothesize to find include changes in knee flexion, knee valgus, and increased time to stabilization after fatigue. We also hypothesize the 30-second side hop, lateral hurdle hop, and chair to box task will have good between session reliability.

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Imitation of COPD Breathing in Healthy, Young Individuals

Emma Leone, William Denton, Farahnaz Fallah Tafti, Jennifer Yentes, PhD
Department of Biomechanics, University of Nebraska at Omaha, Omaha, NE USA
Email: eleone@unomaha.edu

Presentation Preference: **Poster**

INTRODUCTION

Chronic obstructive pulmonary disease (COPD) is the third leading cause of death in the United States[1]. While COPD is defined in terms of fixed airflow limitation, COPD is also characterized by the frequent association of disease outside the lung[2,3], such as limb muscle dysfunction[4]. Walking patterns in COPD are periodic as compared to controls[5]; mainly in periodic step length and width patterns. It is feasible that these walking rhythms are periodic due to the coupling that exists between walking and breathing rhythms in humans [6] Patients with COPD have more periodic breathing patterns[7] and exhibit abnormal coupling[8].

What is unknown is whether the abnormal coupling is due to this abnormal breathing pattern. Mimicking COPD breathing can be done by allowing normal inhalation and restricting exhalation. Limiting airflow in healthy individuals will provide insight into relationship between the coupling of breathing and walking and may elucidate valuable information regarding abnormal coupling in COPD. The purpose of this study was to determine the effect of restrictive breathing on coupling.

METHODS

Healthy, young subjects (19-35 years) walked on a treadmill under six walking conditions. After determining their preferred walking speed (PS), subjects were fitted with a mouthpiece that allowed for normal inhalation and restricted the amount of air exhaled. Two additional speeds were used: slow speed, -20% PS, (SS) and fast speed, +20%PS, (FS). Within the three speeds, subjects were recorded with normal breathing (NB) and with restrictive (COPD) breathing (CB) via use of a customized plug. The order of the set of condition pairs was randomized for each participant. In each trial, subjects were asked to walk on the treadmill for 6 minutes with a minimum of two minutes of rest between trials. Most commonly used frequency ratio (MCFR), its percentage, and phase coupling (PC) from discrete relative phase were quantified. Previously collected data from healthy older adults and patients with COPD were also used for comparison.

A one-way repeated measures ANOVA was used to compare all six conditions. To compare healthy young, healthy older, and COPD groups, a two-way, repeated measures ANOVA (3 groups x 3 speeds) was used. For the two-way ANOVA, the COPD breathing condition was used for the healthy young and normal breathing conditions for the older and COPD groups.

RESULTS AND DISCUSSION

MCFR percentage was different between the six conditions ($p=0.02$). Young subjects had less variability in their MCFR during slow walking and normal breathing, compared to preferred and fast restrictive breathing conditions ($p=0.03$ for both). This was also true for slow walking and restrictive breathing compared to fast speed restrictive breathing ($p=0.002$) and between the two fast speed breathing conditions (NB having a greater percentage, $p=0.03$). MCFR and PC were not different between the six conditions.

When comparing the three groups at three speeds, MCFR and MCFR percentage showed significant differences, PC did not. Healthy younger and older adults used a more complex MCFR compared to COPD patients ($p=0.02$). COPD patients relied more on frequency ratios at 1:1 and 1.5:1. This is similar to previous findings comparing COPD to aged-matched controls[8]. Only at PS were healthy young did not have a significantly different MCFR compared to COPD patients. This is likely due to four healthy young subject's inability to couple and having great variability. MCFR percentage demonstrated that healthy older and COPD patients use their most common frequency ratio for a greater percentage of time than the healthy young ($p=0.04$). MCFR percentage decreased as speed increased ($p=0.02$) for all groups.

CONCLUSIONS

Based on these findings, it was not possible to mimick the abnormal coupling found in patients with COPD. Although a similar theoretical approach to restricting breathing was used, healthy young adults were still able to maintain fairly normal coupling during restrictive breathing. It appears that the restrictive breathing may have limited their ability to couple breathing and walking. Future studies should explore other measures of coupling and/or different restrictive methods.

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Individuals with Peripheral Artery Disease Alter Spatiotemporal Gait Parameters When Walking With Pain versus Without Pain

Todd Leutzinger[1], Sara Myers[1], & Iraklis Pipinos[1,2]
[1]Department of Biomechanics, University of Nebraska at Omaha, Omaha, NE USA
[2]College of Public Health, University of Nebraska Medical Center, Omaha, NE USA
Email: tleutzinger@unomaha.edu

Presentation Preference: [**Poster**]

INTRODUCTION

Peripheral artery disease (PAD) is primarily characterized by atherosclerosis in the arteries of the lower legs causing claudication in the form of debilitating pain during walking [1]. Claudication is the result of blockages in the arteries supplying oxygenated blood to working muscles. Past research has shown individuals with PAD display differences in spatiotemporal gait parameters compared to healthy controls and when walking with and without pain [2,3]. The aim of this study was to further investigate spatiotemporal gait adaptation in patients with PAD from the time they begin walking with no pain to walking in maximal pain.

METHODS

Four patients with PAD (height: 1.76 ± 0.062 m; weight: 83.01 ± 15.06 kg; age: 61.5 ± 11.6 years) walked on a treadmill at a self-selected speed for a maximum of three minutes or until they felt claudication pain. Subjects were to notify the researchers immediately once they felt pain. If no pain was induced during this three-minute trial, a 10% incline was added to the treadmill and subjects walked on the incline until claudication was felt. After the subject indicated claudication had occurred, the treadmill was set to zero percent grade and subjects walked while in pain. Subjects walked in pain until they could no longer continue to walk.

Kinematic data were collected via retro-reflective markers placed on each subject at specific anatomical positions utilizing the marker systems of Vaughan and Nigg [4,5]. The first five steps, the first five steps following initial onset of pain, and the last five steps from the pain condition were identified using Cortex version 6 (Germantown, MD, USA). Cadence (steps/minute), step length (m), stride length (m), swing time (s), and stride time (s) were calculated at each of the three different time-points of the walking trial for each subject's most affected leg.

RESULTS AND DISCUSSION

Changes in cadence, stride length, step length, swing time, and stride time indicate patients with PAD modify spatiotemporal gait parameters between walking with and without pain, but alter spatiotemporal parameters very little when walking with maximal pain compared to at the onset of pain. (Table 1). Average stride time for each walking condition is displayed in Figure 1.

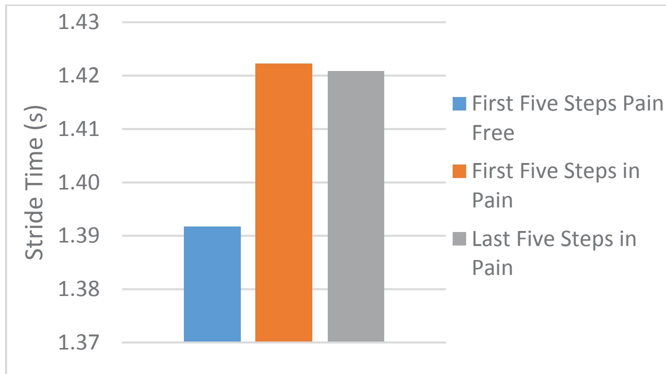

Figure 1: This graph shows the average stride time for the most affected leg across all subjects in each walking condition. The blue bar refers to the first five steps in the pain free condition, orange bar refers to the first five steps in the pain condition, and gray bar refers to the last five steps in the pain condition.

CONCLUSIONS

The results of this abstract indicate patients with PAD initially alter spatiotemporal gait parameters between walking with and without pain, but there are little to no changes while walking in maximal pain. The trends from this abstract support that of Gardner et al., but more subjects will need to be analyzed to confirm these results [3].

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Table 1: This table displays the average cadence, stride length, step length, swing time, and stride time of the most affected leg for each subject across walking conditions.

	Cadence (steps/minute)	Stride Length (m)	Step Length (m)	Swing Time (s)	Stride Time (s)
First Five Pain Free	89.94 ± 18.83	1.01 ± 0.21	0.51 ± 0.13	0.44 ± 0.11	1.39 ± 0.37
First Five Pain	88.34 ± 19.51	1.04 ± 0.22	0.53 ± 0.14	0.44 ± 0.12	1.42 ± 0.39
Last Five Pain	88.87 ± 20.22	1.04 ± 0.22	0.54 ± 0.14	0.44 ± 0.10	1.42 ± 0.41

SIMULATED EVALUATION OF HUMAN-IN-THE-LOOP EXOSKELETON OPTIMIZATION TO REDUCE GAIT VARIABILITY IN PATIENTS WITH PERIPHERAL ARTERY DISEASE.

Philippe Malcolm[1], Sara Myers[1], Iraklis Pipinos[2]
[1]Department of Biomechanics, University of Nebraska at Omaha, Omaha, NE USA
[2]Department of Surgery, UNMC, Omaha, NE USA

email: pmalcolm@unomaha.edu, web: https://www.unomaha.edu/college-of-education/cobre/

Presentation Preference: **Poster**

INTRODUCTION

Peripheral Artery Disease (PAD) affects approximately 10 million Americans [1] and is produced by atherosclerotic blockages in the arteries supplying the legs. The most common manifestation of PAD is ischemic leg pain, gait dysfunction and decreased ability to walk. Myers et al. demonstrated an average 34% increased variability at the ankle joint quantified using Lyapunov Exponent (LyE) in PAD patients [2]. Traditional PAD treatments such as revascularization operations, medication and exercise therapy do not sufficiently restore walking biomechanics and variability [3]. We have previously demonstrated that exoskeletons can reduce the LyE in able bodied participants [4]. Additionally, recent studies have shown that human-in-the-loop algorithms that automatically optimize the actuation pattern towards a certain objective (e.g. metabolic cost) are highly effective and require less walking time from the participant [5,6] which would be an important advantage for PAD patients. The aim of this abstract was to evaluate if a future human-in-the-loop exoskeleton optimization algorithm could potentially reduce LyE by an amount that corresponds to the average increase in LyE in patients with PAD.

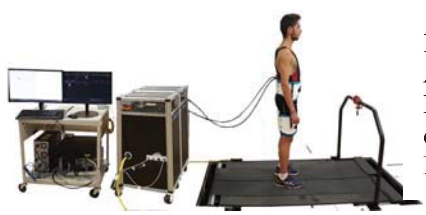

Figure 1: Anticipated setup. Hip exoskeleton in development by Humotech.

METHODS

For future experiments we plan to use a hip exoskeleton that is currently in development by Humotech (Figure 1). In the present analysis we have used LyE data from an experiment in which 10 healthy young participants walked with ankle exoskeletons with 10 different actuation magnitude and timing combinations [7]. In this data we have analyzed how a gradient descent algorithm that starts from an actuation timing of 42 % and an actuation magnitude of 0.4 W kg^{-1} could converge towards the minimum and if this could provide a reduction in LyE larger than the amount that corresponds to the increase in LyE in patients with PAD.

RESULTS AND DISCUSSION

We found that LyE could be reduced by an amount that is greater than 34 % compared to walking with the exoskeleton powered off in 9 out of 10 participants (Figure 2). We also found that in 8 out of 10 participants a human-in-the-loop algorithm would likely converge towards the overall minimum while in 2 participants there appeared to be multiple local minima for the effect of timing on LyE. A limitation of this preliminary analysis is that it is based data of healthy participants walking with ankle exoskeletons which is different from our intended application of a hip exoskeleton for PAD patients. We plan to start pilot testing the hip exoskeleton in patients with PAD in mid-2018. Nevertheless, the analysis of results in individual participants shows that in most participants it is possible to reduce LyE by a clinically relevant amount.

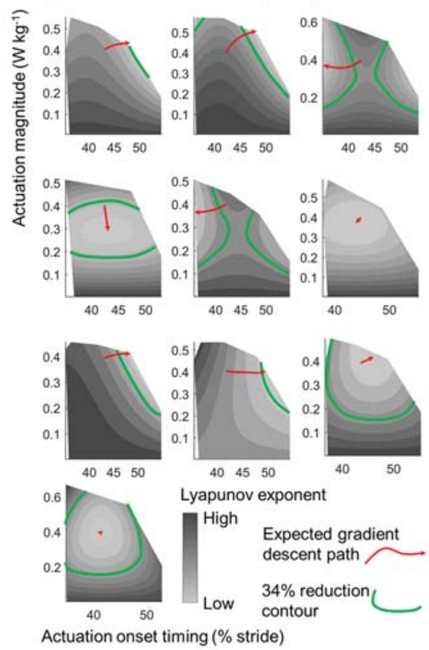

Figure 2: Simulated evaluation of human-in-the-loop optimization. Contour plots are data from 10 participants.

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INTER-LIMB COORDINATION IN CHRONIC STROKE SURVIVORS

Zachary Motz, Troy Rand, Mukul Mukherjee
[1]Department of Biomechanics, University of Nebraska at Omaha, Omaha, NE USA
email: zmotz@unomaha.edu web: https://www.unomaha.edu/college-of-education/cobre/
Presentation Preference: Poster

INTRODUCTION

Every year, more than 795,000 people in the United States have a stroke. This is the leading cause of disability in adults and more than half of stroke survivors have reduced mobility.[1] Current rehabilitation practices often fail to correct gait deficits. One key deficit found in stroke survivors is gait asymmetry.[2] While gait asymmetry characterizes individual differences between the legs (e.g. step time or step length differences), gait coordination characterizes interactions between the two legs (e.g. durations of similar behavior or repeating patterns). In a healthy system, coordination allows our legs to effectively work together providing a smooth and efficient gait.

Defining and understanding the temporal structure of gait patterns in chronic stroke survivors may be the key to creating a successful rehabilitation paradigm. One tool that can help in understanding the temporal structure of variability is cross-recurrence quantification analysis (cRQA) which allows us to quantify the strength of coordination over time (maximum line length) between the two limbs.[3] Another measurement to define inter-limb coordination is Cross-Sample-Entropy (cross-SampEn), which quantifies the regularity of patterns in a pair of time series. Larger values represent lower coordination, while lower values indication greater synchrony.

The goal of this project was to determine the temporal structure of inter-limb coordination in chronic stroke survivors.

METHODS

12 patients with hemiparesis due to stroke were recruited from the Nebraska Stroke Center. Participants walked on a split-belt treadmill for a familiarization period in which their preferred walking speed (PWS) was determined. The participants then walked for as long as they could, and up to 5 minutes at their PWS. Cross-SampEn and cRQA were used to characterize temporal structure of variability.

RESULTS AND DISCUSSION

Over the course of 150 steps, it can be seen (fig.1) that one chronic stroke survivor has greater inter-limb step-length asymmetry than the other chronic stroke survivor. This is further exemplified when examining the cRQA values. Larger cRQA values represent greater durations of coordination, thus, the participant with a more symmetric gait should have longer coordination durations, which is displayed (cRQA max line=2377 and 805, respectively). Figure 2 shows twelve chronic stroke survivors' level of symmetry plotted against their max-cRQA value.

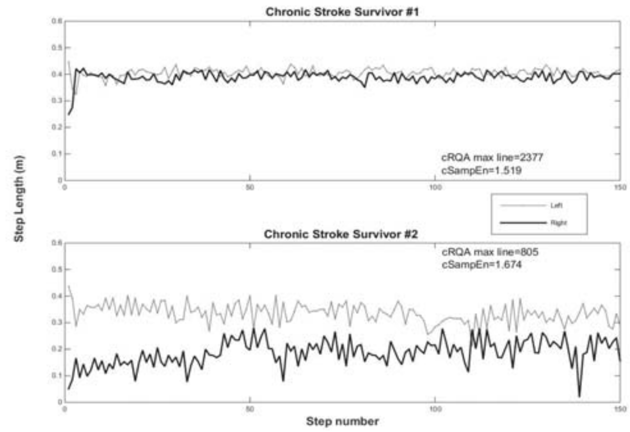

Figure 1: Raw data from pilot subjects and their corresponding cRQA max line and cSampEn values

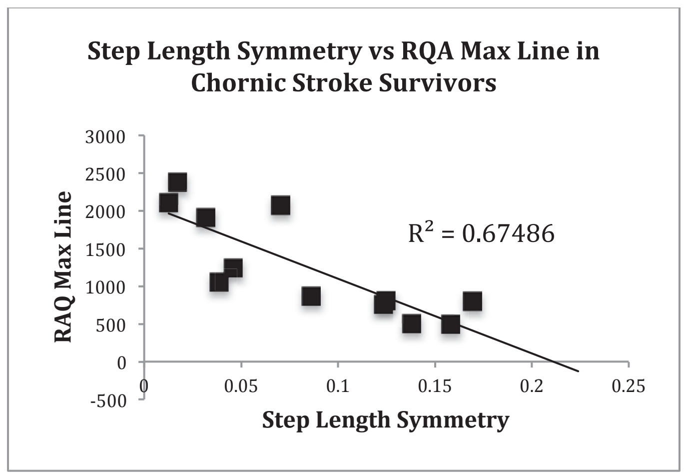

Figure 2: As level of asymmetry increases in chronic stroke survivors RQA max line decreases.

CONCLUSIONS

Nonlinear methods have been used to describe complex conditions in which linear techniques have been inadequate and can help in developing more meaningful measures to identify problems missed in the past. cRQA and Cross-SampEn provide us with a better understanding of inter-limb coordination differences and are variables that could be targeted for rehabilitation in chronic stroke survivors.

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THE RELATIONSHIP BETWEEN LINEAR AND NONLINEAR ANALYSIS ON ACTIVITY DATA

Katlyn J. Nimtz, Abderrahman Ouattas, Brian A. Knarr
Department of Biomechanics, University of Nebraska at Omaha, Omaha, NE USA
email: knimtz@unomaha.edu, web: cobre.unomaha.edu

Presentation Preference: **Poster**

INTRODUCTION

The Center of Disease Control reports that 16% of older adults meet the recommended activity levels.[1] Older adults who do not achieve a high level of fitness, adapt a low intensity level activity, like walking. A popular method to measure walking activity is using activity monitors. Activity monitoring is a reliable way to observe physical activity without interfering with their daily life or relying on self-reported activity. We can analyze activity data using linear and nonlinear analysis, which provide unique insight into behavior.

Linear analysis is traditionally used to quantify activity through measures such as average daily steps or standard deviation of daily steps.[2,3] Nonlinear analysis measures how data changes over time and can provide insight into physical activity behavior by analyzing patterns of their movement, which linear measures cannot detect.[2]

The purpose of this study is to determine the relationship between linear and nonlinear analysis of daily activity in older adults. We hypothesize that total daily activity (i.e. daily steps) will show a correlation with the temporal (nonlinear) structure of daily activity. Secondly, we hypothesize linear variability in daily activity (i.e. standard deviation of daily steps) will show no correlation with the temporal (nonlinear) structure of steps between days.

METHODS

Eight participants (73 ± 4 years, 2M 5F) were recruited for this preliminary study. For data collection, each participant was given an ActiGraph GT9X Link (ActiGraph, Pensacola, FL) to wear around their belt as close as possible to their center of mass for 7 days. Participants were instructed to wear the device during all waking house even if they stayed at home. The only time the device was not worn was if they were in or around water (i.e. bathing, swimming). The device started collecting at midnight on Day 1 and stopped collecting at midnight on Day 8. Step counts were recorded and exported in 5-second epochs using the ActiLife data analysis software (ActiGraph, Pensacola, FL) for analysis.

Linear analysis was performed using a custom MATLAB (MathWorks, Natick, MA) code to export average total step count, average steps per day, average steps per bout, average active time, and average bout duration. Nonlinear analysis was performed using the Jensen-Shannon Divergence (JSD) on the step count series. Jensen-Shannon Divergence is an algorithm that measures similarity on multiple signals, in this case, day-to-day activity over a 7-day period. For each 15-second epoch, the similarity between days was determined for each of the seven days of activity.

RESULTS AND DISCUSSION

Preliminary results have been collected from seven out of the eight participants. One participant was excluded as only six of the 7 days were collected from the ActiGraph.

Over a 7-day period, a correlation was observed between the average steps per day and the Jensen-Shannon Divergence at 15-second epoch ($p<0.05$, $r^2=0.45$), but not between average total step count, average steps per bout, average active time, and average bout duration and JSD at 15-second epoch (**Figure 1**).

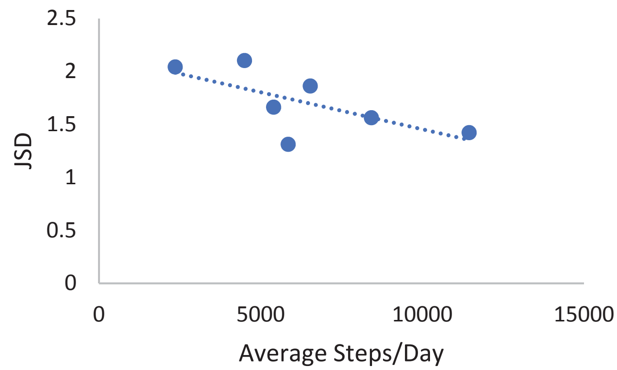

Figure 1: The correlation between average steps per day and the Jensen-Shannon Divergence.

From our preliminary results, we can see a negative correlation between average daily steps per day and the day-to-day similarity in activity patterns as assessed by JSD. This suggests that older adults who are more active maintain a more similar structure of activity from day to day. However, we did not see a correlation between linear variability in daily activity and JSD. Standard deviation measures the amount of variability over the entire day, while JSD observes the variability of activity though analyzing inter-day patterns, while accounting for the temporal structure of activity. Therefore, it is not surprising that no direct correlation between measures was observed.

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THE EFFECTS OF ADDED BODY MASS ON FOOT MECHANICS AND THERMOREGULATION

Jeffrey Patterson[1], Nikolaos Papachatzis[1], Andrew Kern[1], Dustin R. Slivka[2], Iraklis I. Pipinos[3] & Kota Z. Takahashi[1]
[1]Department of Biomechanics, University of Nebraska at Omaha, Omaha, NE, [2]School of Health & Kinesiology, University of Nebraska at Omaha, Omaha, NE, [3]Department of Surgery, University of Nebraska Medical Center, Omaha, NE
email: jmpatterson@unomaha.edu, web: https://www.unomaha.edu/college-of-education/cobre/

Presentation Preference: [**Poster**]

INTRODUCTION

The ankle-foot system produces nearly equal amounts of positive and negative work during steady-state walking, analogous to a spring [1]. However, structures distal to the hindfoot (i.e., the toes, metatarsophalangeal joints, heel pad, etc.) primarily absorb energy during stance and then generate or return a smaller amount of energy during push-off, producing net negative work production overall [1]. The effect of this net negative work behavior of the foot is not well understood, but could have health implications. It may be possible that the net negative work at the foot is being transferred into heat, which would lead to increasing foot temperatures during walking [2]. If uncontrolled, this temperature increase could damage the skin and lead to ulceration [3].

The goal of this study was to determine if the foot's mechanical behavior is related to its temperature regulation. By adding mass to individuals while they walked on a treadmill, we attempted to manipulate the amount of positive and negative work produced. We hypothesized that: 1) walking with added mass would lead to a greater increase in foot temperature (compared to no added mass), and 2) the change in foot temperature (from no added mass to added mass conditions) will be correlated with the change in net work (from no added mass to added mass conditions).

METHODS

18 subjects (age = 24.6 ± 2.8 years, height = 1.75 ± 0.06 m, mass = 85.3 ± 21.1 kg) signed an informed consent form and participated in the study. Subjects walked barefoot over a walkway embedded with force plates while a 3D motion capture system tracked the motion of their lower limbs. Subjects also walked for 10 minutes on a treadmill in the same motion capture volume. Both overground and treadmill walking conditions (1.25 m/s) were performed (in randomized order) with three levels of added mass: 0% (no added mass), 15%, and 30% of body mass using a weight vest. Before each treadmill walking trial, participants' legs were sprayed/wiped with 70% isopropyl alcohol, after which they rested for 30 minutes. Then, baseline temperature measurements were recorded using a handheld thermometer (Extech SDL200, Extech Instruments, Boston, MA). Measurement sites included: heel pad, plantar aspects of the 1st and 5th metatarsal heads and hallux, dorsal surface of the 1st and 5th metatarsal heads, anterior and posterior shank, anterior and posterior thigh, and a core temperature measurement using a tympanic thermometer. The same temperature measurements were repeated immediately after each treadmill walking trial.

Mechanical power of the foot was quantified using a unified deformable segment analysis by modelling structures distal to the calcaneus as a deforming body [1]. Positive and negative work were calculated by integrating power data with respect to time over the stance phase of overground walking.

RESULTS AND DISCUSSION

Starting temperatures of the foot (average of all foot sites) for the 0%, 15%, and 30% added mass conditions were similar. A one-way repeated measures ANOVA with Greenhouse-Geisser correction determined that mean change in temperature differed significantly between the added mass conditions ($F(1.873, 31.836) = 4.893$, $p = 0.016$). Post-hoc tests using the Bonferroni correction revealed that 30% added mass elicited greater increases in foot temperature compared to 0% added mass (0%: 1.61 ± 1.65 °C vs. 2.56 ± 1.52 °C, $p = 0.045$).

The change in temperature of the foot between the 0% and 30% added mass conditions on the treadmill was not correlated with the difference in the average net work per step from the overground trials ($p = 0.263$, Figure 1).

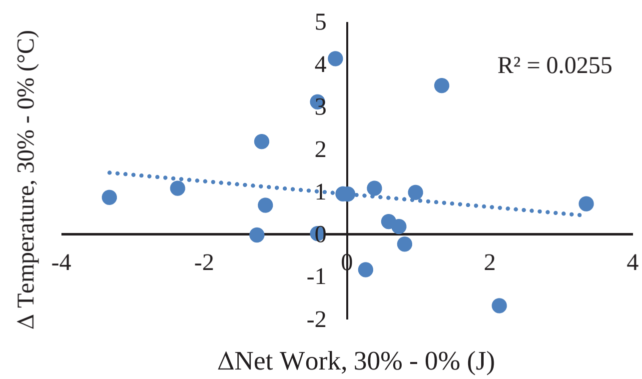

Figure 1: The difference in foot temperature after treadmill walking with 0% and 30% added mass was not correlated with the difference in net work per step while wearing 0% and 30% added mass from the overground trials ($p = 0.263$).

CONCLUSIONS

Future investigations are needed to determine the cause of high foot temperatures during walking, particularly in clinical populations like diabetics and those with peripheral artery disease who are susceptible to ulcer formation [3].

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A NEW METHOD TO TEST HEARING IN CHILDREN WITH MOTOR OR DEVELOPMENTAL IMPAIRMENT

Heather Porter[1], Emily Buss[2], Jenna Browning[1], & Lori Leibold[1]
[1]Boys Town National Research Hospital, Omaha, NE USA
[2]University of North Carolina at Chapel Hill, Chapel Hill, NC USA
email: heather.porter@boystown.org web: https://www.boystownhospital.org/research/HearingResearch/Pages/default.aspx

Presentation Preference: [Poster]

INTRODUCTION

It can be challenging to collect reliable audiological data from listeners with significant motor or developmental impairments [1]. Clinical procedures for testing this population are often time consuming and may be less reliable than methods for testing other listener groups (e.g., older children who are typically developing). Accurate assessment of hearing is no less critical, however.

METHODS

The two-interval procedure developed in our laboratory [2] is based on the single-interval observer-based psychophysical procedure [3]. Each listening interval is indicated to the observer (via computer monitor and speaker), but the observer is blinded to which interval contains the signal. The observer selects the interval associated with the signal based solely on the listener's behavior. Correct observer responses are followed by positive reinforcement to the listener, such as illumination and activation of a mechanical toy and social praise.

Testing consists of two phases: 1.) The Conditioning Phase was used to familiarize the observer with listener response behaviors, and the listener learns the relationship between the presentation of the stimulus and the reinforcement. 2.) In the Training (Criterion) Phase, the probability of the stimulus being presented in either interval is 0.50. Reinforcement is provided only if the observer correctly identifies the interval that contains the signal. Criterion is reached when the observer scores 8 out of the last 10 responses correct.

The signal is either a 1000-Hz warble tone or a pre-recorded spondee (playground), spoken by a male talker.

RESULTS AND DISCUSSION

Data for three listeners with cerebral palsy are shown in Table 1. All subjects reached the 80%-correct criterion in a single session, indicating that the child-observer team reliably and accurately identified supra-threshold sounds. One listener produced two well-formed adaptive tracks (Figure 1), suggesting that reliable estimates of thresholds can be obtained using this procedure.

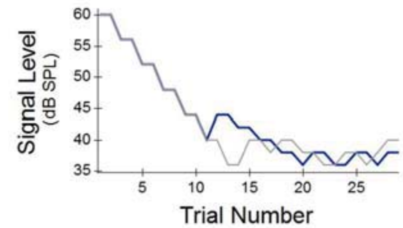

Figure 1: Two adaptive tracks using a two-up, one-down stepping rule [4] to obtain an estimate of the signal level required to achieve 70.7% correct detection.

This procedure has the advantage of providing an estimate of performance that is not biased by tester expectations about a child's abilities. Given that all three listeners reached the 80%-correct criterion, it is anticipated that the two-interval observer-based procedure could improve reliability for behavioral evaluation of children with developmental abilities.

More participants are needed to better quantify the applicability of the two-interval observer based procedure to test hearing in children with motor or developmental impairments. Future studies are warranted to assess how estimates of threshold using the two-interval observer-based procedure compare to those collected during the course of clinical care.

CONCLUSIONS

Preliminary results suggest that using a two-interval forced choice procedure is feasible for testing children with motor and developmental impairments.

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Table 1: Data obtained during test sessions for individual listeners.

	age (years)	criterion achieved (Y/N)	trials to criterion	threshold obtained (Y/N)
Listener 1	14	yes	9	no
Listener 2	14	yes	8	yes
Listener 3	7	yes	14	no

The Effects of Vibrations on the Light Touch Perception Threshold of Transtibial Amputees

Aaron Robinson [1], Jenny Kent[1], Shane R. Wurdeman[2], Adam L. Jacobsen[3], Nicholas Stergiou[1, 4], Kota Z. Takahashi[1]
[1]Department of Biomechanics, University of Nebraska at Omaha, Omaha, NE USA
[2]Department of Clinical and Scientific Affairs, Hangar Clinic, Houston, TX USA
[3]Veterans Affairs Medical Center, Omaha, Ne USA
[4]College of Public Health, University of Nebraska Medical Center, Omaha, NE USA
Email: ajrobinson@unomaha.edu
Presentation Preference: Poster

INTRODUCTION

Persons with transtibial amputations have reported difficulty in walking, standing, and have higher risk of falling [1]. This difficulty, in part, could be associated with the lack of sensory feedback from the prosthesis. Sensations deriving from the residual limb and the prosthetic socket interface may be important for mobility/balance following an amputation. One potential way to improve sensation in the residual limb-socket interface is the use of sub-threshold vibrations. Stochastic resonance is a mechanism that occurs when a weak signal is potentially increased by the application of a larger random signal [2]. Traditionally, white noise vibration is the most common form of stochastic resonance. The utilization of a sub-threshold white noise vibration can help reduce postural sway in young and older adults [3]. However, this paradigm has not been used with amputees to enhance sensation in the prosthetic side. Furthermore, it is possible to achieve superior benefits by using a sub-threshold pink noise vibration, where the intensity is inverse to the frequency of the signal. The use of a sub-threshold pink noise vibration could produce better results due the presence of 1/f structure abundantly in biological signals. Furthermore, a prior study has shown that pink noise is more superior to white noise in detecting the efficacy of a weak signal in sensory nerves [4]. The purpose of this study was to determine whether the use of sub-threshold vibrations can improve the light touch sensation in the residual limb of transtibial amputees. We hypothesized that the application of a subthreshold pink noise vibration will improve an amputee's ability to perceive a light touch stimulus in the residual limb surrounding the area of the amputation.

METHODS

20 unilateral transtibial amputees (ages 59.7±15 yrs) and seventeen healthy control subjects (ages 54.1±16 yrs) participated in this study. For transtibial amputees, light touch sensation threshold (LTST) was tested under baseline first and then 3 different conditions randomly presented: 1) no vibration, 2) white noise vibration, and 3) pink noise vibration. The baseline and the three conditions were administered to the mid-thigh of the residual limb by a vibrating tactor. Subjects were instructed to lay on their backs wearing headphones and a screen was used to block view of light touch. The baseline was tested first, and the order of the 3 conditions was randomized. We quantified the LTST on the tibial crest using monofilament testing [5]. The monofilaments varied from a diameter of 1.65mm to 6.65mm. The monofilament diameter of 5.07, is used as the reference for the protective sensory threshold (PST) [5]. The participant's LTST was established by use of the 4-2-1 stepping algorithm [6]. This algorithm used the repeated responses to increased stimuli and the lack of responses to a decreased stimulus to determine the LTST. The points where participants shifted from detecting the stimuli to not be recorded and averaged. Both controls and transtibial amputees were required to have at least 4 shifts to be averaged. The amputees were split into 2 groups, those who averaged above the PST (n=8) and those who averaged below the PST (n=8). The baseline LTST of healthy controls and transtibial amputees was compared using an independent t-test. Within amputees, the LTST was compared across the 3 different conditions, using a one-factor repeated measures ANOVA ($\alpha=0.05$).

RESULTS AND DISCUSSION

The LTST was significantly greater in amputees than healthy controls ($p<0.001$). The vibrations did not significantly influence the LTST in amputees ($p=0.44$), regardless of whether the individuals were above or below the PST (fig 1). The results from the current data set do not fully support our hypothesis. We are currently testing whether sub-threshold vibrations can improve function beyond light touch perception, such as walking/standing using biomechanics-based analyses.

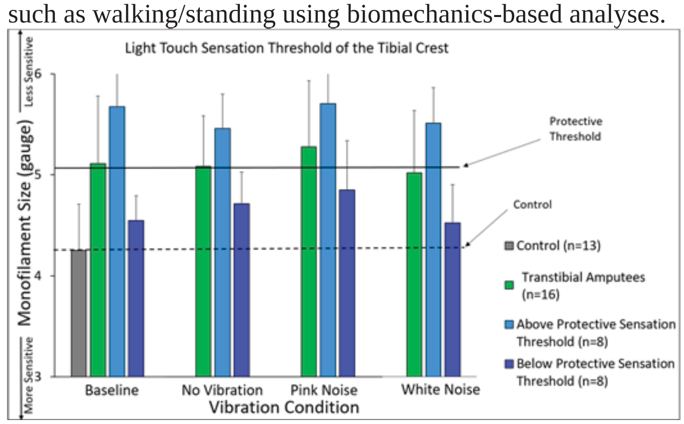

Figure 1: The application of vibrations (white and pink noise) had no significant effect on the light touch in the residual limb (tibial crest) of individuals with transtibial amputation (p=0.44)

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Fractal scaling of visual metronomes affects cortical hemodynamics

Douglas A. Rowen[1], Joao R. Vaz[1], Nick Stergiou[1,2]
[1]Department of Biomechanics, University of Nebraska at Omaha, Omaha, NE USA
[2]College of Public Health, University of Nebraska Medical Center, Omaha, NE USA
email: darowen@unomaha.edu, web: https://www.unomaha.edu/college-of-education/cobre/

Presentation Preference: [**Poster**]

INTRODUCTION

Walking is one of the most important activities of daily life as it is needed to maintain independence and quality of life. A common rehabilitation approach to improve walking involves using an audio or visual external cue (e.g. metronome) to provide patients with spatial or temporal information on when or where to step. Previous research has shown that individuals are capable of synchronizing their steps with a metronome [1,2] and in pathological populations, improvements to gait characteristics have been shown [3]. More recently, metronomes with different temporal structures that rely on fractal based flucuations (i.e pink noise) have been shown to more closely resemble natural walking [1,4]. It is unknown however, how walking to a metronome impacts the brain, and if any changes in cortical hemodynamics, blood flow to the brain, occur when walking to a metronome. Thus, the aim of this study is to investigate the changes in blood flow in the brain as a result of walking with different metronomes to determine if fluctuating metronomes produce different responses in blood flow than periodic metronomes. We hypothesize that the pink noise metronome will produce less blood flow in the supplementary motor areas and motor cortex than either a white noise, randomly fluctuating, or periodic metronome.

METHODS

3 subjects (26.33 ±3.3 yrs.) walked four, ten minute trials on a treadmill while wearing a 4x4 fNIRS probe (Hitachi ETG-4000) to measure brain activity. In addition, footswitches (Noraxon) were worn to determine gait events. They walked to three different visual metronomes: periodic, white noise and pink noise. Prior to the metronome trials, a ten minute trial was recorded to determine the cadence and deviation for the metronomes. FNIRS data was recorded and filtered using a low pass filter at .5 Hz. Footswitch data was recorded to accurately identify heel-strike events. Inter-stride intervals were then calculated from heel-strike times. Detrended Fluctuations Analysis [5] was used to calculate the fractal-scaling.

RESULTS AND DISCUSSION

The results of the present study are in line with the previous literature [1] showing that the fractal scaling of pink-noise metronome (0.89±.14) is similar to the self-paced (0.80±.1) condition, while white-noise (0.50±.06) and periodic (0.36±.1) metronomes exhibit lower values of fractal-scaling (Figure 1).

Although this is a preliminary analysis of hemodynamic data, the results of this study do not fully corroborate our hypothesis that pink-noise metronome would exhibited less blood flow in the SMA and MC areas. All three metronomes resulted in an increase of activity in the Prefrontal cortex (PFC) and Supplementary motor areas (SMA). Only the white metronome

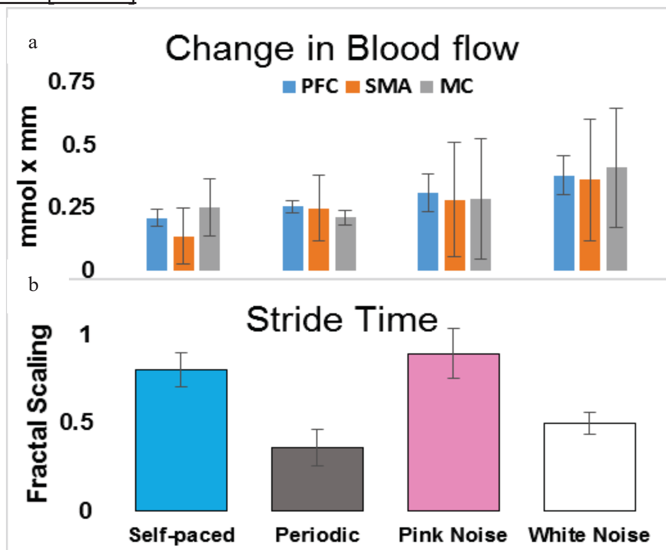

Figure 1: a) Changes in oxygenated blood flow for the three regions of interest. b) Stride time fractal scaling for all four conditions.

showed increases in the Motor cortex (MC). The increases in the PFC and SMA were possible due to walking with a metronome may resemble a dual task activity which results in additional brain activity in those regions [6]. The white metronome seemed to result in the largest increase in all regions of the brain. This may be due to the unpredictability of the fluctuation in the white metronome which may cause more attention to the task.

CONCLUSIONS

Regardless of the temporal structure of the metronomes, the blood flow increased in the PFC and SMA. More subjects need to be collected to understand if the current preliminary findings in terms of largest increase with white-noise metronome are significant and correlates to changes in stride time fractal-scaling values. This may indicate that the temporal structure of the metronome may impose different attentional demands for an individual to remain synchronized with the metronome.

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Passive Exoskeleton Enhanced Temporal Component of Gait Adaptation in a Split-belt Adaptation Task

Takashi Sado[1], BS, James Nielsen[1], BS, Troy Rand, MS[1], Brian Glaister[2], MS, Kota Takahashi[1], PhD., Philippe Malcolm[1], PhD., Mukul Mukherjee[1], PhD.
[1]Department of Biomechanics, University of Nebraska at Omaha, Omaha, NE USA
[2]Cadence Biomedical, Seattle, WA USA
email: tsado@unomaha.edu, web: https://www.unomaha.edu/college-of-education/cobre/

Presentation Preference: [**Poster**]

INTRODUCTION

Unilateral sensorimotor pathologies like stroke can lead to gait asymmetry. One way to counter this challenge is by using assistive devices such as exoskeletons. An active (powered by external sources) exoskeleton is known to be more efficient and accurate in its assist, but it is expensive, less portable, and may require technical assistance to use. . A passive exoskeleton (self-powered) can be a favorable choice for local or home rehabilitation settings because it is cheap, light weight, and less complex to utilize.

While there is research that investigates the benefits of exoskeleton on gait patterns, there have been no investigations into how such devices assist with gait adaptation. This is important because diseases like stroke, substantially impair adaptation, such that recovery becomes difficult. In this study young healthy subjects were recruited with the objective of determining characteristic gait adaptation patterns that result from exoskeleton usage during a split-belt adaptation task.

METHODS

Eighteen healthy young participants were randomly divided into EXO (n=9), and NO EXO (n =9) group. Individuals in EXO group wore a passive exoskeleton [2] on their right leg. Each participant performed the split-belt adaptation task on the treadmill, where the speed of each belt was controlled independently. Participants self-selected their preferred walking speed (PWS) and fast walking speed (FWS). Slow walking speed (SWS) was calculated as half of the FWS. Trials included baseline, split-belt adaptation, and post-adaptation trials. For the split-belt adaptation task, the ratio of fast belt to slow belt was 2:1 [1].

Spatiotemporal variables, including step length, step time, limb excursion, stride time, stance time, and double support time were calculated to quantify adaptation. For each variable, inter-limb symmetry was quantified using symmetry indices (SI). To analyze the adaptation, trials were divided into the early adaptation (EA), late adaptation (LA), de-adaptation (DA), and transfer effect (TR). Additionally, all treadmill trials were analyzed using a group x condition 2-way ANOVA for significant differences (p<0.05)

RESULTS AND DISCUSSION

Spatial Variables: Condition main effects were significant for EA, LA, DA and TR; however, group and interaction effects were significant only for DA adaptation condition.

Temporal Variables: Group, condition and interaction effects were significant for EA, LA and DA for temporal variables, especially stance time. Therese results showed that the exoskeleton assisted gait adaptation influenced on temporal component of gait variables more than spatial component.

Use of an exoskeleton allowed early attainment of adaptive changes compared to NO EXO. Additionally, exoskeleton use allowed stable de-adaptation in EXO group compared to NO EXO group (Figure 1).

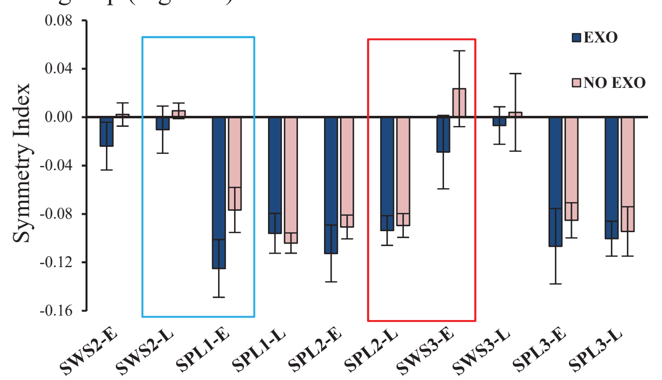

Figure 1: Stance time average symmetry index of first and last 5 steps of each trial. Early attainment of adaptation task can be seen in the left rectangle, and de-adaptation can be seen in right rectangle.

CONCLUSIONS

Characteristic patterns associated with split belt adaptation were affected when adaptation was done with passive exoskeleton assistance. Future studies should investigate if such patterns can also be observed with active assistance and if gait adaptation in stroke survivors could be enhanced with exoskeleton-assistance.

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DEVELOPMENT OF LOW COST 3D PRINTED ANATOMICAL MODELS FOR PRE-SURGICAL PLANNING

David Salazar[1], Drew Dudley[1], James Pierce[1], Keaton Young[1], Jorge Zuniga[1], Justin Cramer[2], Gabe Linke[3]
[1]Department of Biomechanics, University of Nebraska at Omaha, Omaha, NE USA
[2]Department of Radiology, University of Nebraska Medical Center, Omaha, NE USA
[3]Children's Memorial Hospital, Omaha, NE USA
email: dsalazar@unomaha.edu

Presentation Preference: **[Poster or Podium]**

INTRODUCTION

Three-dimensional (3D) printing is a process of making a 3D solid object of virtually any shape from a digital model. 3D printing is achieved using an additive process, in which successive layers of material, such as plastic, are laid down in different arrangements. Previous investigations have demonstrated the feasibility and utility of 3D printing in a wide range of subspecialties of medicine, such as the development of low-cost 3D prostheses [1]. Modeling and printing techniques have also been used in the development of various anatomical structures [2].

The ultimate goal of this research is to develop and publish a low-cost methodology of how to develop low cost anatomical models for pre-surgical planning of highly complex surgeries. This low-cost production has a high potential impact in underserved medical populations, especially those with less access to advanced technologies.

METHODS

In order to produce the models, a 3D representation of the structure must be created with a specified software, and then printed by a 3D printer. To compare the different model possibilities, structures will be prepared by 2 different types of software (industrial and open-source), and 3 different types of printers (high end, intermediate level, and low-cost), resulting in a total of 6 different models.

The proprietary software used to develop the model files is the Mimics program (Materialise Interactive Medical Image Control System; Materialise, Leuven, Belgium: $32,000 per year), and the open-source software used is the 3DSlicer program (Brigham and Women's Hospital, Boston, MA: free).

Various quality printers and materials ranging from high-end, intermediate level, and low-cost were used to produce the models for accurate comparison. The high-end professional 3D printer is the the OBJET260 Connex3 (Stratasys, Inc. Eden Prairie, MN; cost $158,900.00). The intermediate level 3D printer is the uPrint SE Plus (Stratasys, Inc. Eden Prairie, MN; cost $26,934). The low-cost 3D printer is the Ultimaker 2 extended (Ultimaker B.V., Geldermalsen, The Netherlands; cost $ $2,999). In addition, different materials were used for the manufacturing process, such as resin base materials (high-end professional 3D printing material $530, per pack of 3.6 kg), Acrylonitrile Butadiene Styrene (ABS; intermediate level 3D printing material $50 per pack of 1 kg), and Polylactic acid (PLA; low-cost 3D printing material $20 per 1 pack of 1 kg).

Once all the 3D models were produced, they were presented to a licensed radiologist in a single-blind study for accuracy of representation of the region of interest and overall quality.

RESULTS AND DISCUSSION

In a blind preliminary analysis of the 3D printed models, a licensed radiologist was asked to review each of the models and determine which he felt to be a "better representation of the region of interest". His observation found that the models printed by the free open-source 3DSlicer software were preferred to those prepared by the Mimics software. Additionally, our methodology resulted in a significant cost reduction from $30,000 to $1,000. The cost estimations are rough approximations of the software and equipment cost.

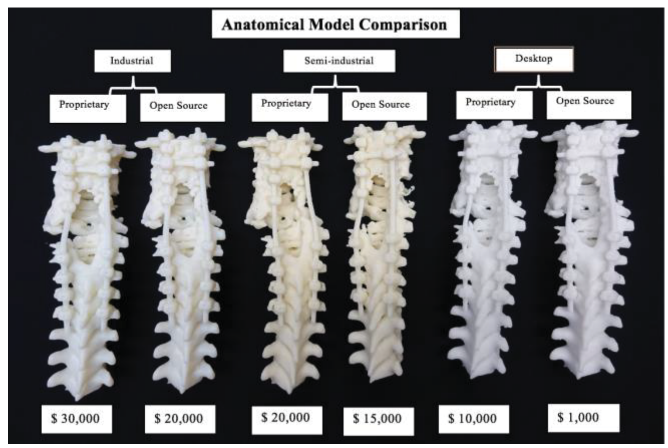

Figure 1: Low-cost methodology for the development of anatomical models for pre-surgical planning. From left to right: Anatomical models of a section of the spine using proprietary versus open source software and industrial 3D printers, semi-industrial, and desktop (low-cost) 3D printers. Engineering time not included in pricing.

ANTICIPATED RESULTS

For future evaluations, a clinical team including radiologists and surgeons will validate, evaluate, and compare the anatomical models against original clinical imaging data. Each anatomical model will be ranked in terms of preference of use in the operating room. Since the free open-source software was the more accurate model for the radiologist, this could be a potential indicator that the low-cost development is not only useful for surgical planning, but also as good as or even superior to the proprietary software.

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Non-linear analyses for assessing static and dynamic variability using smartphone sensor data

Mason Schleu[1], Brian Knarr[2]
[1]Department of Electrical and Computer Engineering, University of Nebraska at Lincoln, Lincoln, NE USA
[2]Department of Biomechanics, University of Nebraska at Omaha, Omaha, NE USA
email: mschleu@unomaha.edu

Presentation Preference: Poster

INTRODUCTION

Balance disorders impact over 35% of Americans, causing a substantial impact on quality of life due to psychological and physical hardships associated with poor balance [1]. Balance disorders can affect anyone of any age, and range in seriousness from slight dizziness to the inability to safely walk from place to place. Most prominently susceptible are older adults, where injury from falling is a prevalent and grave concern. Studies show that once a certain age is reached, the chance of falling begins to increase exponentially every year. Starting at 30% at the age of 65 the risk of falling doubles once the age of 70 is passed. 20% of these falls lead to serious injury [2], and 27,000 fatalities occur every year as a result [3]. The purpose of this study is to determine if a low cost, self-service mobile sensor system is reliable in detecting balance performance during standing and walking tasks. This study uses non-linear analysis, through the calculation of sample entropy during standing, and maximum Lyapunov exponent's during walking to assess static and dynamic stability.

METHODS

To accomplish the scientific objective of this study, 11 young, healthy subjects have been recruited to perform both a static and dynamic balance assessment. Participants in this study completed the six stances of the Balance Error Scoring System (BESS) test for a standing balance examination and then proceeded to a six-minute walking trial on an indoor track for dynamic data collection.

During both standing and walking trials, a smartphone with a custom data collection application is strapped to the participants waste, near their center of mass. The custom application records tri-axial acceleration and angular velocity and logs the data to a local file for external analysis.

Data analysis is performed using custom MATLAB code. Sample entropy is computed for each of the six BESS stances and maximum Lyapunov exponent of the center of mass acceleration is calculated for middle 30 seconds the six-minute walking trial.

RESULTS AND DISCUSSION

The average maximum Lyapunov exponents (LyE) of all 11 subjects walking data were calculated using the middle 30 seconds of the walking trial to facilitate comparison to previous studies [4]. The greatest LyE, or least stability, was found in the medial-lateral direction (Figure 1). Values from our phone application were found to be slightly greater than previous studies, which used XSENS sensors to collect pelvic acceleration [4]. It is likely that our data included a greater amount of noise due to the quality of the accelerometer used in the smartphone. Further investigation on filtering the smartphone data is warranted.

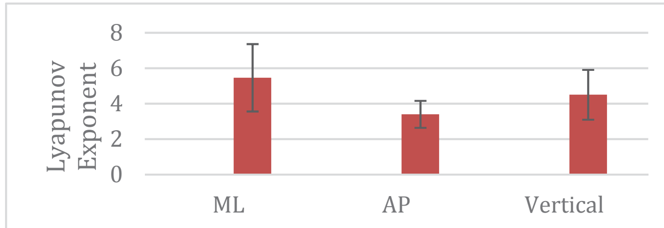

Figure 1: Maximum LyE values for the medial-lateral, anterior-posterior, and vertical directions during overground walking.

The average sample entropy of all 11 subjects is shown for each of the six BESS balance test stances (Figure 2). Here, stances two and five display the least regular postures. Both are the single leg stance on different surfaces. Similar to the LyE data, we observed greater values in Stance 1 of the BESS balance test when compared to previous literature using research grade accelerometers [5].

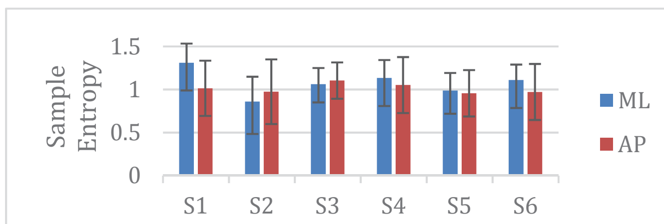

Figure 2: The most variable postures are shown to be stances 2 and 5 in standing tests.

CONCLUSIONS

Previous research has shown the potential for smartphone sensors to collect continuous data for balance using static methods [6]. This study shows the technology to be promising using more sophisticated, nonlinear analysis and in the use of dynamic testing.

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ALTERED GAIT VARIABILITY DOES NOT AFFECT HEART RATE DYNAMICS IN YOUNG ADULTS

Joao R. Vaz[1], Jenny Kent[1] & Nicholas Stergiou[1,2]
[1]Department of Biomechanics, University of Nebraska at Omaha, Omaha, NE USA
[2]College of Public Health, University of Nebraska Medical Center, Omaha, NE USA
email: jvaz@unomaha.edu, web: https://www.unomaha.edu/college-of-education/cobre/

Presentation Preference: **Poster**

INTRODUCTION

Physiological systems can be entrained by internal rhythms. The coupling between locomotor and cardiac rhythms has been observed to be enhanced in older adults[1]. This enhanced cardiolocomotor coupling, observed in older adults may represent a protective mechanism that benefits cardiovascular performance and cerebral perfusion in older adults[1]. The output of each of these systems is characterized by a certain temporal structure in young healthy adults, that indicates health. A breakdown in this temporal structure, on the other hand, has been observed with aging in both systems[2,3]. Walking to either a periodic (no variability) or a random (too much variability) metronome also alters stride-to-stride temporal structure towards values typically observed in older adults[4]. The present study aims to investigate how changes in stride-to-stride temporal structure affects heart rate temporal structure during walking in healthy young adults. We hypothesized that when stepping to a metronome that changes the temporal structure of stride-to-stride intervals, heart rate dynamics will be similarly be altered as a mechanism of maintaining coupling.

METHODS

Seventeen healthy young adults (23.3±3.3yrs) walked for 25 minutes at their self-selected walking pace on a treadmill wearing a chest mounted heart rate monitor with in-built accelerometer (Zephyr Bioharness 3.0). Participants were then asked to walk for a further 25 minutes, synchronizing their stepping with one of three auditory metronomes: 1/f (pink-noise; n = 4), random (white-noise; n = 7) and periodic (n = 6). A custom-made MATLAB code was used to calculate the inter-stride intervals (ISIs) and R-R intervals from the accelerometer and ECG data respectively. The time series of these intervals were used to calculate the ∝ fractal scaling, using Detrended Fluctuation Analysis[5], to determine the statistical persistence within each time series. For the R-R intervals, two different scales were used and then ∝-short and ∝-long was calculated. Non-parametric statistical tests were used to determine differences between groups and conditions (stimulus ON or OFF) in ISIs, and between conditions in R-R intervals.

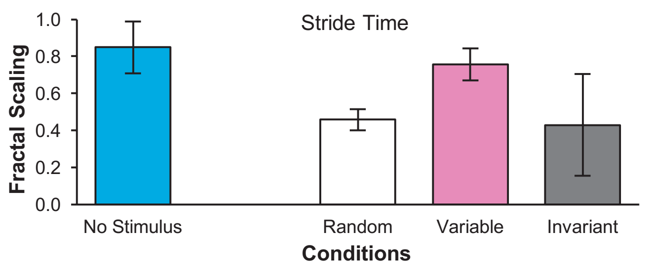

Figure 1. Figure 1. Inter-stride intervals fractal scaling for each group. 'No stimulus' bar represents the average of the subjects from the three groups.

RESULTS AND DISCUSSION

Inter-Stride Intervals. Significant statistical differences were observed in the random (p=0.018) and periodic (p=0.028) between stimulus and no stimulus condition, and no differences were observed for the 1/f metronome. The comparison between metronomes with stimulus ON showed significant higher fractal scaling in the 1/f metronome compared to both periodic (p=0.026) and random (p=0.014) metronomes (Figure 1). *R-R Intervals*. No differences were observed between stimulus ON and OFF in all the three groups, in both ∝-short and ∝-long (Figure 2). Contrary to our hypothesis, these preliminary results suggest that changes in the temporal structure of walking does not affect heart rate temporal structure. This may be due to the robustness of the cardiovascular system or simply because young adults do not require this coupling.

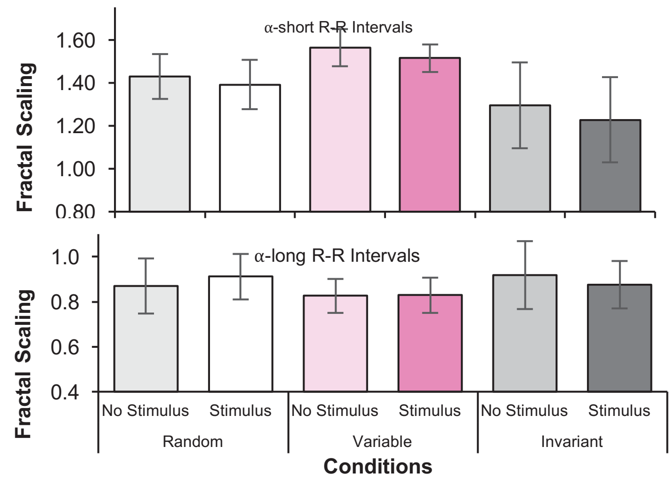

Figure 2. Short- (upper panel) and long-fractal scaling (bottom panel) for RR intervals, for each group.

CONCLUSIONS

This preliminary study suggests that the cardiovascular system is not affected by alterations in gait temporal structure in young unimpaired adults. Conducting the same study in a group of older adults may elucidate whether the enhanced coupling observed is driven by locomotor or cardiovascular systems.

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FORWARD POSTURAL LEAN MODULATES COMMON NEURAL INPUT TO UNILATERAL AND BILATERAL PLANTAR FLEXOR MUSCLES

Tatsunori Watanabe[1,2], and Kotaro Saito[1]
[1]Department of Physical Therapy, Nagoya University Graduate School of Medicine, Nagoya-shi, Aichi JAPAN
[2]Japan Society for the Promotion of Science, Chiyoda-ku, Tokyo JAPAN
email: watanabe.tatsunori@h.mbox.nagoya-u.ac.jp

Presentation Preference: [**Poster**]

INTRODUCTION

During quiet standing, the involvement of the cortex in postural control is relatively small, and bilateral plantar flexor muscles receive common neural input supposedly from the subcortical system [1,2]. On the other hand, maintaining a forward postural lean position has been shown to induce the cortical activity [3]. Considering the cerebral lateralization, it can be expected from these findings that the unilateral cortical control and synchronous bilateral activation of plantar flexor muscles would need to be adjusted efficiently and effectively during the forward postural lean. However, how bilateral plantar flexors are controlled unilaterally and bilaterally has not been clearly elucidated yet. In this regard, we asked in this study whether forward postural lean would affect the common neural input to unilateral and bilateral plantar flexor muscles, using a coherence analysis.

METHODS

A total of fourteen young adults (mean age ± SD = 22.6 ± 0.9) participated in this study. They stood on a force plate with their bare feet parallel and were asked to perform two tasks: quiet standing and forward lean tasks. In the quiet standing task, they were instructed to stand quietly while looking at a fixation sign on a PC monitor set in front of them. In the forward lean task, the subjects were instructed to lean the body forward by dorsiflexing at the ankle joints while keeping the rest of the body straight. A green horizontal target line representing a 75% of the maximum forward lean distance and two yellow horizontal lines at +5 % and -5% of the target line were displayed on the PC monitor. The subject's COP position was also presented on the PC monitor as a red line progressing from left to right, which moved upward/downward as the subject leaned forward/backward. The Subjects were asked to keep the COP on the green target line and within the yellow lines. The task duration was 40s, and the order of the tasks was randomized among the subjects. The electromyograms were recording bilaterally from the medial gastrocnemius (MG) and soleus (SL) muscles.

The standard deviation (SD) and mean speed of the anteroposterior center of pressure (COP) sway were compared between tasks using a paired t-test. Also, the coherence between the unilateral and bilateral plantar flexor muscles was examined. The coherence was calculated for the following muscle pairs: right MG–right SL, left MG–left SL, right MG–left MG, and right SL–left SL. The z–transformed coherence was averaged over a beta band, that reflects the corticospinal drive [4], for the unilateral coherence, and over a delta band, that is associated with the synergistic activity of contracting muscles [5], for the bilateral coherence. The coherence is a number ranging from zero to one: zero indicates that two signals are completely independent, and one indicates that two signals are identical. The significant coherence was identified by 95% confidence limit. The averaged coherence was compared between tasks using a paired t-test. The correlation between the COP parameter and the strength of coherence was additionally calculated using Pearson's correlation coefficients.

RESULTS AND DISCUSSION

The SD of COP sway was marginally smaller in the forward lean than quiet standing task (p = 0.076). The speed of COP sway was larger in the forward lean than quiet standing task ($p < 0.001$).

Figure 1 presents results about the z-transformed coherence. The beta–band unilateral coherence was larger in the forward lean than quiet standing task for both right and left leg (right: p = 0.0025, left: p = 0.0073). The delta–band bilateral coherence was smaller in the forward lean than quiet standing task for both right MG–left MG (p = 0.014) and right SL–left SL pairs (p = 0.0063). The SD of COP sway was positively correlated with the delta-band bilateral coherence for the right SL–left SL pair.

The results suggest that the subjects have decreased the common input to the bilateral plantar flexor muscles and increased the corticospinal drive to the unilateral plantar flexor muscles when leaning the body forward. Also, it appears that the smaller the bilateral common input was, the better the postural performance was. The smaller variability in postural sway may be attributed to the neural modulation.

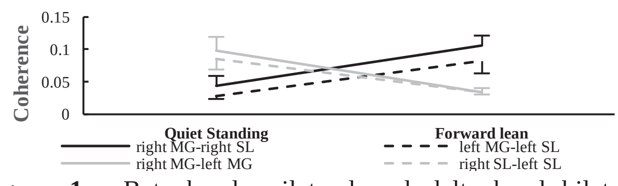

Figure 1: Beta–band unilateral and delta–band bilateral coherence.

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STANDING POSTURE IS RELIABLE ACROSS DAYS AND WEEKS IN HEALTHY, YOUNG ADULTS

Jordan Wickstrom, M.S., Lauren Wehrle, Alyssa Averhoff, & Jennifer Yentes, PhD
Department of Biomechanics, University of Nebraska at Omaha, Omaha, NE USA
email: jfwickstrom@unomaha.edu

Presentation Preference: **Poster**

INTRODUCTION

Static posturography refers to techniques used to quantify postural control in a quiet, upright stance. A simple paradigm for evaluating postural control is using a force platform to measure center of pressure (COP), which measures body sway[1]. COP has been used to describe how posture is organized[2]; describing the point of application in which the sum of all forces is acting between the body and the ground. Researchers have employed COP in studies examining standing posture in healthy and unhealthy adults as well as in children[3-4]. Although many studies have examined postural control, no study has investigated how reliable posture is over time. This is necessary in order to use posture as a potential diagnostic or assessment tool. Therefore, the purpose of this study was to determine the reliability of standing posture across multiple days in healthy, young adults.

METHODS

39 adult subjects (ages 20-31yrs; 23m, 16f) participated in eight visits occurring at the same time of day. The first five visits occurred over five consecutive days (e.g. Mon-Fri) to evaluate day-to-day reliability, and the subsequent three visits occurred one week, two weeks, and three weeks after the first visit to examine week-to-week reliability. At each visit, subjects stood on a force platform in a stenciled position and participated in four, two-minute conditions with a two-minute sitting break between each one: 1) shoes on with eyes opened (SEO), 2) shoes on with eyes closed (SEC), 3) barefoot with eyes opened (BEO), and 4) barefoot with eyes closed (BEC). All trials were randomized to control for order effects, and eyes-opened trials required participants to focus on a fixation cross at eye-level. The dependent variables were root mean square and range in the anterior-posterior (AP) and medial-lateral (ML) directions, sway path excursion, circle area, and ellipse area. Intraclass Correlation Coefficient (ICC) was used to assess reliability. Values >= .700 indicated high reliability.

RESULTS AND DISCUSSION

Across all eight visits, ICC (3,8) values for posture in the BEO condition were the most reliable for all dependent measures (all ICC values>=.700; see Table 1). Eyes closed conditions and conditions with shoes were less reliable (inconsistent) across all visits.

When examining the day-to-day variability (i.e. visits one through five), ICC (3,5) values for BEO trials were also the most reliable. For the other conditions (i.e. BEC, SEO, and SEC), all ICC (3,5) values were inconsistent (ICC values<.700) except for root mean square in the ML direction for the BEC condition (i.e. ICC=.786). However, when removing the fifth day from the day-to-day variability (only examining days one through four), all ICC (3,4) values were >.821 across all conditions for all dependent measures, suggesting high consistency in posture across consecutive days. Thus, it appears that participants' posture was less reliable on the fifth day compared to the other visits. Since most participants' fifth visit occurred at the end of the week (e.g. on Friday or Saturday), this inconsistency in posture may be due to tiredness or boredom with the protocol.

For the week-to-week reliability (i.e. visits one, six, seven, and eight), all ICC (3,4) values were >.756 across all conditions for all dependent measures, suggesting high consistency in posture across weeks.

Table 1: ICC values across all eight visits. Asterisked values indicate highly reliable ICC (3,8) values (>.700).

	ALL 8 VISITS			
	BEO	BEC	SEO	SEC
RmsAP (mm)	0.895*	0.436	0.411	0.612
RmsML (mm)	0.944*	0.903*	0.780*	0.580
RangeAP (mm)	0.951*	0.802*	0.677	0.464
RangeML (mm)	0.909*	0.271	0.294	0.431
SwayPathExcursion (mn	0.914*	0.036	0.057	0.057
CircleArea (mm^2)	0.936*	0.115	0.055	0.029
EllipseArea (mm^2)	0.936*	0.287	0.121	0.062

CONCLUSIONS

Standing posture in healthy, young adults was reliable across four consecutive days and four consecutive weeks, with the fifth consecutive day leading to inconsistencies. Testing posture during one single visit should therefore be representative of one's typical posture. Barefoot trials with eyes opened are recommended to collect the most reliable data.

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SOFTWARE-BASED TRAINING TO ENHANCE STUDENT LEARNING IN BIOMECHANICS

[1] TeSean Wooden, [1] Angel Gonzalez, [1] Sidney Baudendistel, [1] Amelia Lanier, [1] Michelle Friend, [1]Anne Karabon, [1] Nealy F. Grandgenett, [1] Kota Z. Takahashi
[1] University of Nebraska at Omaha, Omaha, NE, USA
email: twooden@unomaha.edu, web: https://www.unomaha.edu/college-of-education/cobre/

Presentation Preference: [**Poster**]

INTRODUCTION

The study of Biomechanics is inherently interdisciplinary. Biomechanics may be a valuable tool in promoting STEM education within undergraduate students. For example, students who may have an interest in professions related to the health field could acquire a new perspective on how the human body produces movement by being introduced to fundamental knowledge of physics and applied mechanics. Regarding students with interests in technology, engineering, physics, or mathematics, they too could gain an appreciation for all professions within the health field by learning to apply Biomechanics principles. With the continued growth of the field, evidenced by founding of the National Biomechanics Day in 2016, and to ensure the interest within all manner of STEM-related backgrounds, it is imperative that innovative approaches to instruction of the subject continue to improve and evolve.

At the University of Nebraska at Omaha (UNO), we have implemented software-based training to supplement traditional lecture-based teaching. We have redesigned an existing course that was initially catered to those with backgrounds in Exercise Science, Physical Education, Athletic Training, and Biomechanics. The redesigned course emphasized hands-on computer-based training to facilitate active learning within undergraduate students.

The purpose of this study was to examine the effect of software-based training of Biomechanics on undergraduate student performance. We hypothesized, that following the completion of this course, students will: 1) show greater awareness of Biomechanics' role in STEM related fields, and 2) exhibit improved self-confidence of fundamental Biomechanics' concepts.

METHODS

We have adapted an existing undergraduate course in Biomechanics at UNO. This course was initially offered in the Fall of 2016. Twice a week, the class met for a lecture that was one hour, as well as weekly laboratory that was two hours in length. The laboratory sessions included introduction of Visual3D software (C-Motion Inc., Germantown, MD). Each week the students were exposed to a new topic related to Biomechanics-based computation in Visual3D software.

After being exposed to the software, students progressed with assignments that were designed to challenge their critical thinking skills. Students were also asked to analyze the effects of a simulated reduced gravity environment on human walking. To conclude the semester, students were tasked with completing a final project. This Clinical Gait Analysis project included real-world walking data from patients with unique movement disorders. The students were also asked to synthesize the patient's movement limitation, using Visual3D and Biomechanics-based concepts.

To evaluate student performance, we developed a questionnaire to assess the students' overall knowledge of Biomechanics and their awareness of its role in STEM related fields. The questionnaire included a narrative response, and questions based on a Likert scale. Students were asked to complete a questionnaire at the beginning and at the end of the semester.

RESULTS AND DISCUSSION

To date, 90 students consented to participate in this study (28 from Fall 2016, 32 from Spring 2017, and 30 from Fall 2017). Following the completion of, the course, students felt more comfortable in describing fundamental concepts (e.g., Newton's Laws) ($p<0.001$, Figure 1). We are currently developing a scoring rubric for narrative responses that demonstrate students' awareness of the role that Biomechanics can play in STEM related fields.

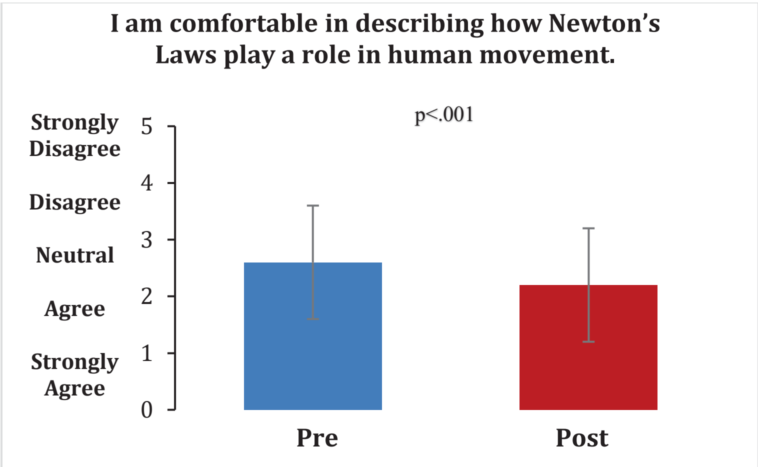

Figure 1: Following the completion of the software-integrated course, students became more comfortable in computer-based problem solving and concepts fundamental to Biomechanics (N = 90). The questionnaires were completed at pre (blue) and post-semester (red).

ACKNOWLEDGEMENTS

This work was supported by funding from NASA Nebraska Space Grant and by the University Committee for the Advancement of Teaching at UNO. We would like to thank C-Motion Inc., and Dr. Saryn Goldberg for sharing data files.

Measurement of Muscle Oxygen Saturation of the Gastrocnemius of Healthy Controls

Ybay, Henamari, Molly Schieber, Iraklis Pipinos[1,2], & Sara Myers[1,2]
Department of Biomechanics, University of Nebraska at Omaha, Omaha, NE USA
Veterans Affairs Medical Center, Omaha, NE USA
email: hybay@unomaha.edu

Presentation Preference: **Poster**

INTRODUCTION

Peripheral Artery Disease (PAD) is a cardiovascular condition caused by blockages of the leg arteries that reduces blood flow. Claudication, a cramping pain or tiredness in the ischemic legs, is the most prevalent symptom associated with PAD that impairs patient walking ability [1]. Oxygen delivery in the leg muscles is likely an important determinant of claudication and functional problems in these patients. In order to learn more about the oxygen muscle saturation in patients with PAD, we must first understand the typical healthy response.

METHODS

This study, utilized MOXY Muscle Oxygen Monitors, a wireless sensor that uses spectroscopy to measure the muscle oxygen saturation in the body. This monitor was attached to the gastrocnemius of ten healthy subjects (56.6 ± 8.9yrs; 177.86 ± 5.3cm; 80.82 ± 8.7kgs). A healthy ankle-brachial index was defined as being greater than or equal to 1.0 [2]. To obtain a baseline, the subject began the trial with a seated rest for 3 minutes. These subjects then performed three Gardner maximum walking tests (2.0mph with 2% grade increase every two min). The trials were lengths of 105s, 231s, and 540s to correspond to grouping patterns previously found in patients with PAD. At the end of each trial, the subject rested for 10 minutes, 60 minutes, and 10 minutes respectively. The device was taken off after all three trials.

RESULTS AND DISCUSSION

The average muscle oxygen saturation at baseline was found to be 53.24% (Figure 1). At the start of exercise, oxygen saturation drops at an exponential rate and remains at this low level until exercise stops (Figure 2). In recovery after exercise, oxygen saturation increased to 64.43%, above the baseline on average.

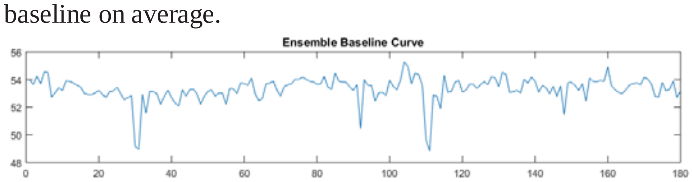

Figure 1: This graph shows the average muscle oxygen saturation found in both legs of all 10 subjects.

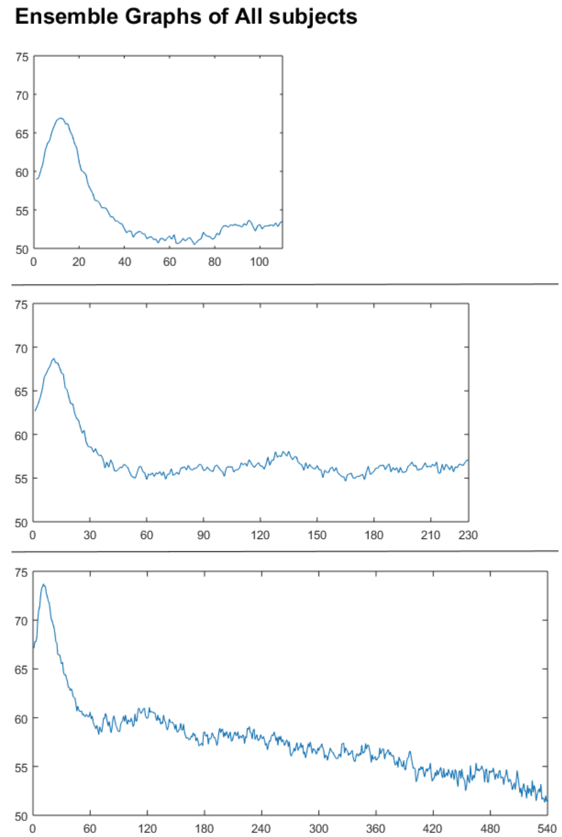

Figure 2: These graphs depict oxygen saturation levels of control subjects during exercise (Top to bottom, Trial 1-3).

CONCLUSIONS

In conclusion, we found that a healthy response to exercise results in an exponential decrease in muscle oxygen saturation. Muscle oxygen saturation will remain at this lower level until rest is initiated. Once at rest, the muscle will experience an increase in oxygen saturation above baseline measurements. Through this study, we have found that the use of MOXY muscle oxygen monitors can be used for studies such as these, however, more tests should be conducted before determining it as a reliable device for medical research.

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Technical, Clinical and Functional Considerations for the Development of 3D Printed Upper-Limb Prostheses

Keaton Young[1], Jean L. Peck[2], Rakesh Srivastava[3], James Pierce[1], Nicholas Stergiou[1], Jorge M. Zuniga[1].
1. University of Nebraska at Omaha, Department of Biomechanics, USA; 2. CHI Health Creighton University Medical Center, Omaha, USA; 3. Innovative Prosthetics & Orthotics, USA .
Presentation Preference: **Poster**

INTRODUCTION

The development of 3D printing for the manufacturing of prostheses and orthoses has resulted in cost reduction strategies, better accessibility and customization of prosthetic designs. The widespread use of 3D printing and the existence of myriad prosthetic designs available on the internet allows clinicians and researchers from different disciplines to manufacture their own devices. Given the dearth of studies discussing the practical application of 3D printed upper limb prostheses, the current paper describes the technical and clinical considerations for the implementation of these devices in rehabilitation and research settings. Specifically, considerations on fitting procedures, assembly, durability, regulatory implications, and patient functional outcomes are discussed.

METHODS

Subjects: Eleven children (five girls and six boys, 3 to 15 years of age) participated in this study and were fitted with a 3D-printed transitional wrist-driven and elbow-driven prosthesis.

Apparatus and Procedures: Gross manual dexterity was assessed using the Box and Block Test and wrist strength was measured using a dynamometer. This testing was conducted before and after a period of 24±2.61 weeks of using a 3D printed transitional prosthesis. The eleven children (five girls and six boys; 3 to 15 years of age) who participated in the study, were fitted with a 3D printed transitional partial hand (n=9) or an arm (n=2) prosthesis.

Data Analysis: Separate two-way repeated measures ANOVAs [2 x 2; hand (affected versus non-affected) x time (before and after)] were performed to analyze function and strength data. An alpha value of 0.05 was considered statistically significant for all comparisons.

RESULTS

	Box & Block Test (blocks per min)*				Flexors Strength (Kg)**			
	Non-affected		Affected		Non-affected		Affected	
ID	Before	After	Before	After	Before	After	Before	After
1	24	25	0	5	10	11.6	8.46	14.6
2	22	26	3	3	11.8	13.46	11.7	13.2
3†	26	27	0	3	---	---	---	---
4	36	38	13	19	4.2	10	5.2	7.6
5†	36	38	0	9	---	---	---	---
6	50	54	40	47	27.53	33.13	17.43	18.9
7†	60	66	0	3	14.8	14.7	25.2	22
8	60	62	13	16	15.7	17.8	12.3	19.46
9	53	53	0	17	24.4	19.4	20.46	22.46
10	69	68	0	9	10.8	10.1	8.3	12.16
11	75	75	0	12	---	---	---	---
M	**46.45**	**48.36**	**6.27**	**13.00**	**14.90**	**16.27**	**13.63**	**16.30**
SD	**18.67**	**18.34**	**12.31**	**12.70**	**7.70**	**7.62**	**6.83**	**5.24**

Table 1. Mean (±SD) for function and strength measurements before and after one to six months of using the 3D-printed hand prosthesis.

There was a significant hand by time interaction for the function [$F(1,10) = 6.42$; $p = 0.03$, $\eta p2 = 0.39$], but not for the wrist flexion strength [$F(1,7) = 0.67$; $p = 0.44$, $\eta p2 = 0.02$], or for the wrist extension strength [$F(1,7) = 0.05$; $p = 0.40$, $\eta p2 = 0.1$]. There were significant main effects of function for the hand [$F(1,10) = 52.41$; $p = 0.01$, $\eta p2 = 0.84$] and the time [$F(1,10) = 37.31$; $p = 0.01$, $\eta p2 = 0.79$]. There were significant main effects of strength for time [$F(1,7) = 6.56$; $p = 0.38$, $\eta p2 = 0.48$].

DISCUSSION & CONCLUSION

The increase in manual gross dexterity suggests that the Cyborg Beast 2 3D printed prosthesis can be used as a transitional device to improve function in children with traumatic or congenital upper-limb differences. The lack of significant increases in strength of the affected limb after using the prosthesis may be related to the small sample size and the large variability in force production among children participating in the present study.

Although durability constraints are factors to consider when using 3D printed prostheses, the practicality and cost-effectiveness represent a promising new option for clinicians and their patients (1-3, 4).

CLINICAL APPLICATIONS

The use of 3D printed transitional prostheses may improve manual gross dexterity in children after several weeks of using it. 3D printed transitional prostheses may play an important role in patient rehabilitation by familiarizing patients to the use and function of the prosthesis.

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