CHANGES IN MUSCLE FORCES AFTER EXERCISE IN PATIENTS WITH PERIPHERAL ARTERY DISEASE

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INTRODUCTION

Peripheral artery disease (PAD) is a manifestation of atherosclerosis that produces blockages in the leg arteries resulting in insufficient blood flow to the lower extremities. This lack of blood flow causes claudication, a cramping-like pain that only gets better with rest. Supervised exercise therapy (SET) is considered as a first-line treatment for claudicating patients with PAD. SET significantly improves peak walking distances and the gait biomechanics at the level of ankle and hip[1]. However, improvement in individual muscle function and muscular response following SET is not well understood. The goal of this project is to implement musculoskeletal computational modeling and simulation to investigate how the SET impacts muscle function. The typical muscular force response to exercise will be quantified.

METHODS

Experimental data collection

Patients recruited for this study participated in a 6-month SET program that followed the American College of Sports Medicine Recommendations[1]. Gait kinematics and kinetics data were collected during the overground walking trials using 8 high-speed infrared camera system (Motion Analysis Corp, Santa Rosa, California). Data were collected before (baseline) and after the SET program (post-exercise).

Musculoskeletal modeling and simulation

We are currently performing the gait simulations in musculoskeletal modeling and simulation platform OpenSim[2] Version 4.0, using a generic full-body musculoskeletal model[3]. First, the anthropometry of this model is matched to that of each subject using the 'Scale' tool (Figure 1). Experimental kinematics and kinetics data are fed into the 'Inverse Kinematics' and 'Inverse Dynamics' tools to calculate the joint angles and joint torques respectively (Figure 1).

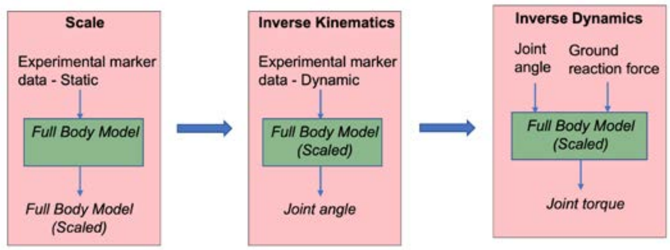

Figure 1: Step by step to calculate the joint angle and torque from experimental kinematics and kinetics data.

Joint angles will be further imported to the 'Residual Reduction Algorithm' tool in OpenSim (Figure 2). The residual reduction algorithm will minimize the effects of modeling and marker data processing errors, called residuals. The outcome measures from residual reduction will be imported to the 'Static Optimization' tool to measure the individual muscle forces during walking (Figure 2). Optimization estimates the muscle forces by minimizing the residuals at each time point in the gait cycle.

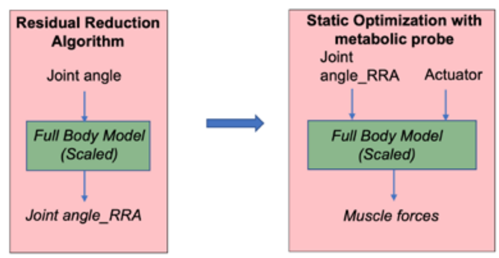

Figure 2: Individual muscle force calculation from joint angles.

EXPECTED RESULTS

Joint torque and calf muscle forces (gastrocnemius and soleus) during the push-off phase of stance will be reported before and after SET. All outcome variables between baseline and post-exercise will be compared by a paired sample-t-test ($p < 0.05$, SPSS Version 26, IBM, Armonk, NY).

The outcomes of this study will provide the fundamental knowledge of how muscle function improves the following exercise and correlates to several gait variables. This knowledge could be useful for future modifications of the rehabilitation protocols that may benefit the patients with PAD most.

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WALKING ABILITY IMPROVES AFTER REVASCULARIZATION IN PATIENTS WITH PERIPHERAL ARTERY DISEASE

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INTRODUCTION

Peripheral artery disease (PAD) is a manifestation of systemic atherosclerosis affecting the leg arteries. PAD results in significantly reduced blood flow to the lower extremities. Open surgical revascularization is recommended for patients for whose walking ability did not improve following pharmacologic and supervised exercise therapy[1]. However, endovascular revascularization is frequently preferred over open revascularization due to its less invasive nature, shorter recovery time, and reduced morbidity[2]. This study aimed to determine how open and endovascular revascularization treatments improve walking ability.

METHODS

Total 42 patients with PAD were recruited for this study. 28 patients underwent open revascularization (age: 61.33 ± 6.15 years, BMI: 27.16 ± 5.09 kg/m^2, ABI: 0.47 ± 0.26) whereas 14 patients underwent endovascular revascularization (age: 64.36 ± 6.71 years, BMI: 27.54 ± 3.61 kg/m^2, ABI: 0.63 ± 0.18). Patients were evaluated before (pre) and six months after (post) surgery. Evaluation included the walking impairment questionnaire (WIQ), six-minute walk test, and the Gardner progressive treadmill test (2mph, begins at 0% grade and increases by 2% grade every 2 minutes). Initial and absolute claudication distances were calculated from the Gardner test. The initial claudication distance was recorded as the first indication of claudication pain. Absolute claudication distance was recorded as the point claudication pain forced subjects to stop walking. Statistical significance was calculated using an ANOVA to determine the main effects of surgery (pre versus post; p_{time}) and surgery type (open versus endovascular; $p_{surgery}$) in SAS (Version 9.4, SAS Institute Inc., Cary, NC, $p < 0.05$).

RESULTS AND DISCUSSION

Time effect (pre vs post)

WIQ scores were significantly improved after surgery ($p < 0.0001$, Table 1). Initial and absolute claudication distance and six-minute walk distance were also significantly increased. These results suggest patients are able to walk further by delaying the onset of pain after surgical treatments.

Surgery type effect (open vs endovascular)

There was no effect of surgery type on WIQ scores (Table 1). However, open revascularization led to more improvement (open: 186.29m, endovascular: 67.88m, p = 0.04) in initial claudication distance but not in absolute claudication distance. This shows that the onset of pain would be delayed for patients who underwent open revascularization surgery.

This study is the first to compare the walking ability between two surgical approaches and provides clinicians with an objective basis for prescribing the most effective revascularization strategy for patients with PAD. Future studies should include the comparisons of biomechanical gait variables between open and endovascular surgical treatments.

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Table 1: Claudication distances and walking impairment questionnaire before and after open and endovascular revascularization. Values are presented as mean (standard deviation).

Dependent Variable	Open		Endovascular		P_{time}	$p_{surgery}$
	Pre	Post	Pre	Post		
Distances (m)						
Initial claudication	58.95 (34.32)	241.20 (208.06)	66.93 (39.48)	143.62 (94.61)	**0.0001**	**0.04**
Absolute claudication	176.07 (102.43)	452.22 (288.36)	206.98 (130.59)	367.83 (239.27)	**<0.0001**	0.16
Six-minute walk	294.50 (85.96)	367.38 (92.65)	322.73 (66.30)	367.50 (66.23)	**<0.0001**	0.66
Walking impairment questionnaire						
Pain	43.52 (18.14)	75.46 (24.88)	40.38 (19.87)	62.50 (29.76)	**<0.0001**	0.19
Distance	42.57 (16.77)	74.90 (20.22)	47.30 (21.54)	78.55 (23.39)	**<0.0001**	0.87
Walking speed	35.50 (24.76)	66.07 (27.55)	40.39 (16.85)	66.19 (34.50)	**<0.0001**	0.80
Stair climbing	43.59 (23.87)	69.07 (27.77)	49.35 (28.50)	66.02 (28.96)	**<0.0001**	0.55

Age-Related Changes of Head Control During Unexpected Perturbations

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INTRODUCTION

Older adults are at significant risk of fall-related traumatic brain injuries (TBI) [1,2]. Older adults with fall-related TBIs have worse health outcomes including extended hospitalizations, and increased morbidity and mortality rates than their younger counterparts [2]. However, there is a limited understanding of the mechanisms relating to increased head impact during falls among older populations [3]. It is possible that age-related changes in head stability predispose older adults to fall-related TBIs. Indeed, it has been documented that older adults have declines in head stability during self-initiated movements [4]. However, there is limited data examining if this decline in head stability is seen in response to external perturbations.

The current study aims to determine if young adults and older adults show differences in linear head jerk (a marker of head stability) during unexpected anterior-posterior perturbations.

METHODS

12 participants without current or past history of neck-related dysfunctions, trauma, deformities and uncontrolled balance issues were recruited. Demographic information is provided in Table 1.

Table 1: Participant Demographics

	Young	Old
Age (years)	19.67 ± 1.36	85.5 ± 2.739
BMI (Kg/m^2)	20.63 ± 2.08	25.96 ± 3.06
Physiological Fall Risk Score	-0.33	1.105

Participants completed three trials of unexpected platform translations in the anterior and posterior directions for a total six trials on the Smart Equitest Research System (Neurocom, USA). An accelerometer (Delsys, USA) was placed on the center of the forehead to measure linear head acceleration in craniocaudal (CC) axis, mediolateral (ML) axis and anteroposterior (AP) axis. Six trials were completed in a randomized order.

Acceleration data was processed by a 4th order Butterworth filter with a cut-off frequency of 5 Hz. A custom Matlab code was used to detect the acceleration recovery period, calculate the zero-crossings, and determine the sum of absolute jerk within the period.

SPSS Version 25 (IBM Inc., Chicago IL) was used for the data analysis. Normality was examined by Shapiro-Wilk test. A non-parametric approach was applied. Effect size (Cohen's d) was also calculated.

RESULTS AND DISCUSSION

The descriptive statistics of zero-crossings and sum of jerk are shown in Table 2. No significant age differences were noted. In the posterior translation, the elderly displayed a trend of increased zero-crossings ($p = 0.093$) and greater jerk in AP ($p = 0.093$). Figure 1 shows the example of the elderly having greater head jerk of the elderly in AP.

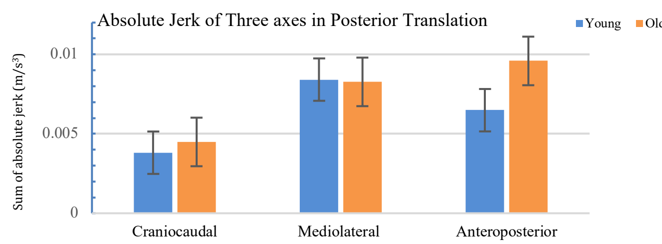

Figure 1: Absolute Jerk (m/s^3) as a function of age group

Similarly, a large effect size shown in Table 3 suggests the increased zero-crossings and larger jerk in the anteroposterior of posterior translation among the old is likely to be true. It is possible that the insignificant between-group difference would increasingly become significant with a larger sample size.

Table 3: Effect size of zero-crossings and sum of absolute jerk in three axes of two translations. $^+$ Represents the large effect size (>0.8).

	Zero-crossings			Sum of absolute jerk		
	CC	ML	AP	CC	ML	AP
AT	-0.7366	0.3229	0.6536	-0.6212	0.2123	-0.0742
PT	0.0575	-0.0742	-0.9626$^+$	-0.4254	0.0351	-1.1188$^+$

Overall, older adults appear to have more zero-crossings and a larger sum of absolute jerk after an unexpected perturbation. Therefore, it is reasonable to propose that the elderly have impaired head stability when responding to an unexpected condition such as a fall. Additional evidence should be investigated to support this hypothesis.

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Table 2: The mean and standard deviation of zero-crossings and sum of absolute jerk in three axes of anterior translations (AT) and posterior translations (PT). * Represents p <0.1.

	Zero-crossings (in numbers)						**Sum of absolute Jerk (*10^{-3})**					
	Craniocaudal, CC		**Mediolateral, ML**		**Anteroposterior, AP**		**Craniocaudal, CC**		**Mediolateral, ML**		**Anteroposterior, AP**	
	Young	**Old**	**Young**	**Old**	**Young**	**Old**	**Young**	**Old**	**Young**	**Old**	**Young**	**Old**
AT	4.17±1.55	5.22±1.31	6.61±2.86	5.94±0.61	4.78±1.42	3.78±1.63	4.99±2.97	6.85±3.01	10.6±6.73	9.51±2.67	7.79±3.95	8.07±3.42
PT	5.39±1.60	5.28±2.21	5.56±2.62	5.72±1.79	2.44±1.66*	3.78±1.04*	3.81±1.06	4.49±1.98	8.41±5.07	8.27±2.80	6.49±3.35*	9.59±2.02*

Restoring arm complexity of stroke patient through arm dyadic synchronization

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Presentation Preference: (**1**)

INTRODUCTION

Stroke patient suffer a reduced ability to use their paretic upper limb and the complexity of this part, and they need rehabilitation programs that require different methods and this is a challenge for therapists[1, 2]. We hypothesized that the reduced ability and loss of complexity could restored based on the complexity matching[3] effect that have been proposed for accounting for synchronization processes and minimize trunk movement [4]. Then our aim was to study to rehabilitate the upper limb, through an experiment that requires prolonged interaction of two systems of different complexities[5], a healthy system and a system lacking in complexity, by arm synchronization in duo.

METHODS

11 participants (10 patients and 1 young healthy companion) were involved in the experiment. They were composed 10 dyad. The experiment lasted eight weeks, with three sessions per week, and three arm synchronize duo sequences of 15 minutes per sessions. At the beginning of the program participants performed, a solo sequence at his/her preferred.

Duo sequences consisted that the participant synchrony their arm with a young arm and healthy companion by bending and extending the arm, along with picking up a cup and the trunk was restricted from the up to reduce its motion. A post-test (solo sequence) was performed after the end of the experiment..

RESULTS AND DISCUSSION

During duo sequences, increased participant's arm movement by increasing the number of repetitions of flexion and extension of the arm and reducing the pain angle.

The restoration of arm complexity was preserved during the post-test, after the end of the experiment..

The results show an improvement in the level of arm complexity matching of stroke patients represented by increased the ability to performance a movement of the affected limb and range motion as result of the complexity matching restoration. This experiment shows that the synchronization experience of complexity matching, with a healthy system, could allow restoring the complexity of deficient systems. Additionally, this effect seems persistent over time, at least within the time scale used in this experiment.

CONCLUSIONS

- Synchronized arm, between stroke patient and the experimenter, is dominated by a complexity matching effect.

-Complexity matching results in an attunement of complexities between the two participants, and an attraction of the complexity of the stroke patient towards that of the younger by increasing arm motion range.

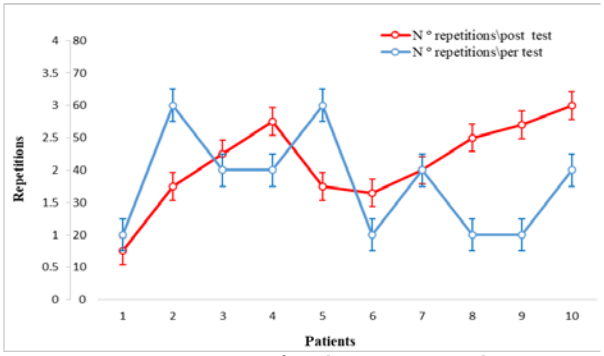

Fig 1. Movement repetitions of Stroke patients per and post test

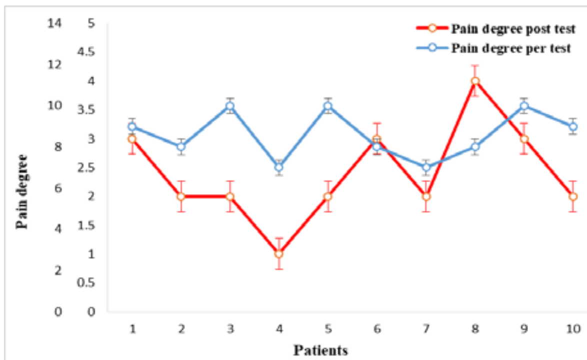

Fig 2. Pain degree of Stroke patient's arm per and post test

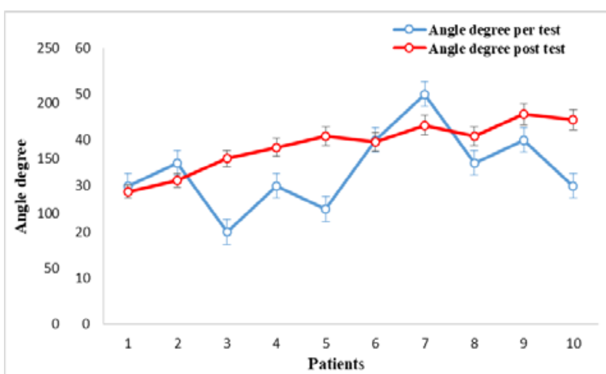

Fig 3. Angle degree of Stroke patient's arm per and

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The Effect of Vision on the Temporal Structure of Center of Pressure Velocity in Stroke Survivors

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Presentation Preference: [Poster]

INTRODUCTION

Stroke is one of the leading causes of long-term disability and stroke survivors are faced with motor deficits that include unstable balance. Typically, healthy individuals are able to maintain balance through sensory feedback. However, with stroke survivors the interaction between the senses is disturbed. This disturbance could be caused by a deterioration in vision. Vision is one of the key senses needed to assist individuals to determine their position and movement through space and maintaining balance. Vision is a major source of information from childhood onward, and a disturbance of this sense can cause other balance-related deficits. It has been shown that stroke alters center of pressure variables during quiet stance (Boumer et al, 2018). However, in a recent study, center of pressure velocity (COPv) was shown to be more sensitive in capturing the characteristics of posture during standing (Rand et al., 2015; 2018). Specifically, vision affects the persistence and anti-persistence properties of COPv oscillations during quiet standing (Rand et al., 2018). Therefore, the purpose of this study was to observe the effect vision has on COPv in a sample of stroke survivors during quiet standing.

It was hypothesized that when visual feedback was absent, both persistent and antipersistent properties of COPv postural oscillations would be affected and this effect would be exacerbated by stroke.

METHODS

Stroke survivors (n=9) and healthy age-matched controls (n=9) performed one-minute quiet standing sessions with either their eyes opened (C1) or closed (C2) while standing on the Smart Balance Master (NeuroCom International Clackamas, OR, USA). During these trials, center of pressure was calculated in the anterior-posterior and medial-lateral positions. Detrended fluctuation analysis was used to analyze the temporal structure of the COPv. This analysis reveals time-scale dependent properties in human behavior which characteristically has a short-scale and a long-scale component separated by an inflection point. Thus our variables included alpha long, alpha short, r^2 long, r^2 short, and inflection of the anterior-posterior and medial-lateral COPv time series (Rand et al., 2018). A two-way repeated ANOVA was performed to measure significant group and condition effects (group: stroke survivors vs. healthy and conditions: C1 and C2) and were further analyzed with post-hoc test if required. Alpha level was set to 0.05.

RESULTS AND DISCUSSION

A significant effect of condition was shown for only the alpha long time-scale in the anterior-posterior direction (p = .035) but no group or interaction effects were evident. Specifically, in the absence of vision, COPv became more anti-persistent in the anterior-posterior direction. This means that in the absence of vision, postural fluctuations became more feedback dependent. This would be necessary to allow the individual to maintain their balance with reliance on other sensory systems**.**

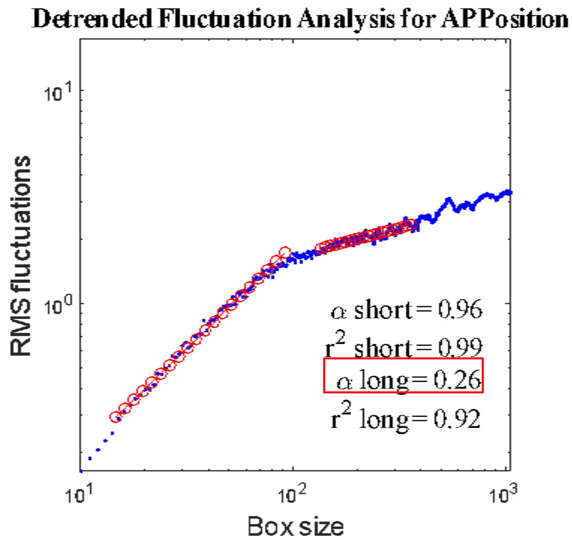

Figure 1 DFA of COP velocity in the anterior-posterior direction of one subject. Only alpha long time-scale had a significant effect between conditions (red box) that characterizes anti-persistent properties in postural dynamics.

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COMPLEXITY OF ISOMETRIC FORCE PRODUCTION – EFFECT OF AGE

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INTRODUCTION

The 'Loss of Complexity' theory by Lipsitz and Goldberger [1] and the later 'Optimal Movement Variability' theory by Stergiou [2], suggest that the complexity of human movements is subject to change following maturation, aging, diseases and injuries. In support of these theories, it is well established that movement complexity is reduced in older adults [3]. However, the theories would also predict that movement complexity is lower in children and adolescents compared to adults. The aim of the present study was to investigate the complexity of isometric force during plantar- and dorsiflexion in healthy children, adolescents, young adults and older adults. Prior to quantification of complexity, the present study investigated whether the structure of the force signals was generated by a linearly auto-correlated Gaussian process, which would suggest a non-deterministic underlying control process.

METHODS

Twelve healthy children (male/female: 5/7; mean±SD age: 9.6±2.2 yrs; height: 1.46±0.18 m; mass: 34.5 ± 9.0 kg), thirteen adolescents (male/female: 9/4; mean±SD age: 15.5±1.8 yrs; height: 1.74±0.09 m; mass: 64.6 ± 10.1 kg), fourteen young adults (male/female: 6/8; mean±SD age: 22.1±1.7 yrs; height: 1.76±0.08 m; mass: 72.5 ± 16.4 kg), and fifteen older adults (male/female: 7/8; mean±SD age: 68.3±2.7 yrs; height: 1.73±0.11 m; mass: 81.5 ± 14.1 kg) were recruited for the present study. The participants completed 2 minutes isometric plantar- and dorsiflexion at 10% of their maximal voluntary contraction force in a seated position with an ankle dorsiflexion angle of approximately 120°. Complexity was quantified using multiscale entropy [5] and surrogate analysis was used to evaluated if the structure of the force signals was generated by a linearly auto-correlated Gaussian process. A one-way ANOVA with group as an independent variable was applied. In case of a significant effect of group, a quadratic regression analysis was completed with age as independent variable and complexity as dependent variable. The overall percentage of variance accounted for by the regression (r^2) was determined. Additionally, Holm-Sidak post hoc test was applied to evaluate between-group differences.

RESULTS AND DISCUSSION

For both tasks, the young adults had significantly higher complexity compared to the two younger groups and the older group (Figure 1). The quadratic regression analysis revealed a significant (dorsiflexion: $p<0.001$; plantarflexion: $p<0.001$) inverted U-shaped relationship (dorsiflexion: $r^2=0.359$; plantarflexion: $r^2=0.285$). This supports the notion that aging is associated with a loss of movement complexity due to the gradual deterioration of the neuromuscular system. Additionally, it suggests that maturation increases the complexity which has been linked to a reduced determinism in the executed motor control [4]. The surrogate analysis revealed that for all participants and all trials, the structure of the force signals did not originate from a linearly auto-correlated Gaussian process excluding a non-deterministic underlying control process.

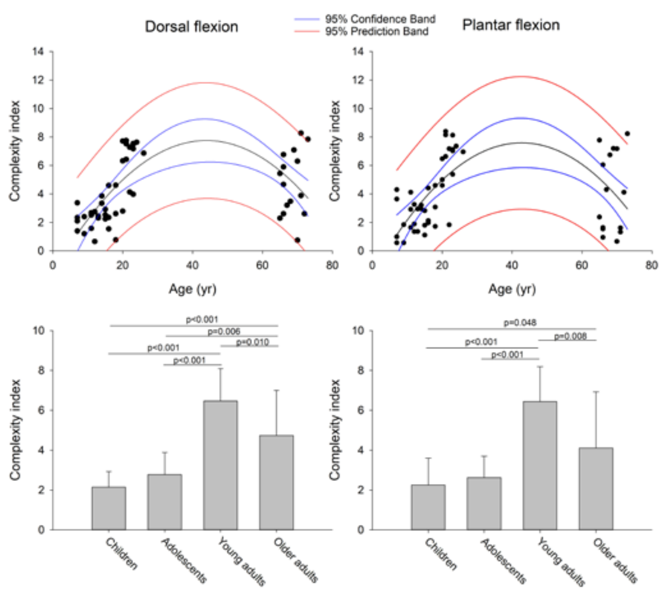

Figure 1: Complexity index for isometric force during dorsal (left graphs) and plantar (right graphs) flexion as function of age (top graphs) and average across age groups.

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Design and development of a semi-rigid bilateral hip exoskeleton

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INTRODUCTION

Robotic exoskeletons can reduce metabolic cost in healthy individuals or could perhaps restore mobility in patients with PAD [1]. PAD is a cardiovascular disease manifesting from atherosclerosis of the leg arteries. The primary symptom of PAD is claudication or pain in the legs during walking that is relieved with rest. About 40% of the metabolic cost comes from the hip muscles [2]. Different groups have been developing rigid exoskeletons and soft exosuits that assist the hip. Assisting at the hip has the advantage that the system mass is positioned closed to the center of mass, which minimizes the penalty of carrying mass. Soft exosuits have the advantage that they allow greater freedom of movement. However, soft exosuits often cannot apply the same torque magnitudes as rigid exoskeletons, and they rely on friction with the skin to remain anchored.

METHODS

We developed a semi-rigid hip exoskeleton for an existing actuation unit system. The exoskeleton does not have a rigid joint, so it allows full freedom of movement. The waist-belt and thigh pieces are semi-rigid. As a consequence of this, they do not solely anchor to the wearer via friction and compression, but they also stay locked on the body as a consequence of the moment from the actuation (Figure 1).

We developed a new high-level temporal force-tracking controller that allows applying a sinusoidal extension and flexion moment profile as a function of the stride cycle percentage on each leg. The timings of heel strikes and toe offs are detected based on the vertical ground reaction force using an adjustable detection force threshold [3]. Since it is not possible to predict precisely when an ongoing walking step will end, the percentage of the step time is estimated based on the timing of the most recent heel contact and a moving average of a number of previous steps. To measure the moment applied to the hip joint, we need to measure the lever arms of the flexion and extension forces, so we can program sinusoidal desired profile versus each percent of the gait cycle.

The low-level controller developed by HuMoTech communicates with the motor and adjusts its velocity to minimize the error between the actual force, which is measured with the load cell, and the desired force using a closed-loop PID algorithm with configurable gains [4].

The actuation unit delivers the extension moment. A set of antagonistic springs delivers the flexion moment. This new design will be tested in experiments aimed at developing faster and more clinically human-in-the-loop optimization algorithms for patients.

RESULTS AND DISCUSSION

We expect to achieve a good match between the desired and actual torque for each leg (Figure 2). To achieve this goal, we need to adjust for proportional, derivative, and damping gains of the controller.

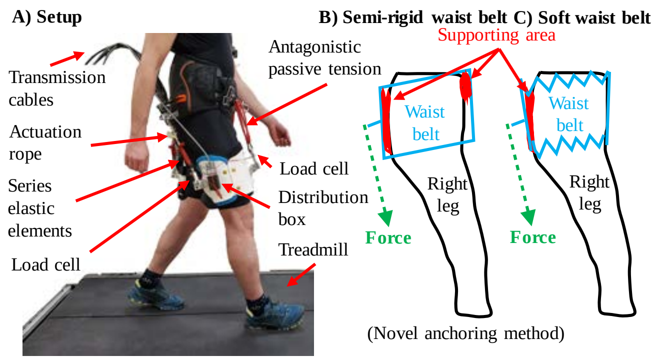

Figure 1: **A)** The hip exoskeleton setup. The waist belt attaches to a person. The two thigh-braces with the loadcells, measure the flexion and extension moment. **B)** Semi-rigid anchoring mechanism: the semi-rigid waist belt anchors to the waist by compression and because it gets stuck when the actuation force tries to rotate the belt. **C)** A soft waist waist-belt would only be able to anchor based on compression.

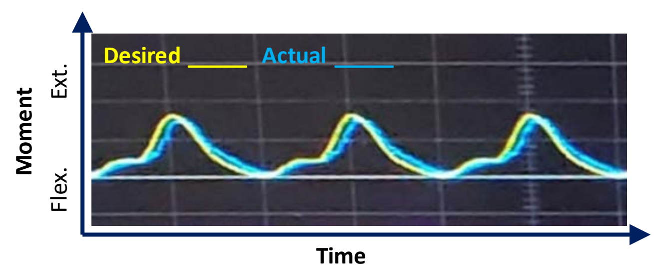

Figure 2: Desired versus actual moment profile. The extension and flexion are increasing and decreasing the amount of the moment.

CONCLUSIONS

We believe the semi-rigid design can have advantages in comfort in patient populations because it requires less friction and compression than soft exosuits.

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CONSIDERATIONS FOR IMPLEMENTING AN ANKLE FOOT ORTHOSIS TO IMPROVE MOBILITY IN PERIPHERAL ARTERY DISEASE

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Presentation Preference: **Poster**

INTRODUCTION

A carbon-composite ankle- foot orthosis (AFO) can contribute to push-off by storing energy from heel strike and subsequently returning force during push-off [1,2]. Thus, an AFO can decrease blood flow demand and muscular stress by substituting for the required ankle plantar flexor torque and power [1]. Peripheral artery disease (PAD) is a manifestation of systemic atherosclerosis, characterized by atherosclerotic blockages of the arteries supplying the legs[1]. Our pilot work has shown that walking with an AFO immediately increases the initial and absolute walking distances in patients with PAD as much as pharmacotherapy for six months[3]. An unanticipated outcome of the pilot was subjects almost immediately deciding whether to adapt or not adapt the AFO as a feasible intervention. Our goal is to assess the unique patient information gathered for feedback related to factors contributing to early AFO intervention withdrawal and AFO use 6 months following the AFO intervention completion and factors contributing to use or disuse.

METHODS

Participants (n=29) were recruited and consented to wear an AFO for 3 months. The length of time the subjects wore the AFO was recorded. The subjects were assessed for early AFO intervention withdrawal and completion. Fifteen subjects completed the study. Six subjects withdrew early before any baseline tests, while eight subjects withdrew from the study after doing baseline tests. Semi-structured interviews were conducted, and data were analyzed using a summative content analysis approach. Results were compared between those who did and did not complete the intervention.

RESULTS AND DISCUSSION

Several key differences in responses were found. 40% of subjects who completed the AFO intervention described their initial reactions to AFO as negative while 50% who dropped out described initial reactions as negative. When asked about amount of time they said they wore the AFO, 33.3% of those who completed compared to 83.3% of those who dropped out reported minimal use of the AFO. Of the barriers to wear there were differences between groups in regard to physical pain and health issues. 46.7 %, and 33.3% of subjects who completed the intervention reported health and physical pain issues compared to 66.6% and 50% of those who dropped out.

CONCLUSIONS

The subset of preliminary data from the AFO intervention will be beneficial towards assessing the implementation success and improvement in quality of life in patients who wore the AFO for three months. In those subjects who did not complete three months of AFO use, their responses help determine the barriers and reason for a lack of adoption.

FUTURE DIRECTIONS

We expect that an AFO intervention will be feasible to implement and improve quality of life for three months for some patients with PAD. However, the results of this study indicate certain patients have barriers to wearing the AFO or other reasons for a lack of adoption. The follow-up study will contact those patients who successfully finished the AFO intervention to determine whether the patients maintained AFO use. Implementation studies will help us determine the factors contributing to AFO intervention withdrawal, identify feasibility and further evaluate what can be potentially improved. Implementation will be assessed using a mixed methods approach guided by RE-AIM, iPARIHS framework and medical outcomes Short Form 36 [6]. Future studies related to investigating the role of telehealth and mHealth in managing these patients can also be explored [4,5].

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ACKNOWLEDGEMENTS

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DETERMINING THE OPTIMAL TENSION FOR KNEE-ANKLE-FOOT ASSISTIVE DEVICE

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Presentation Preference: **Poster**

INTRODUCTION

Peripheral artery disease (PAD) is caused by atherosclerosis, a buildup of cholesterol and fatty acid deposits which blocks blood flow to the arms, legs and feet[1]. This lack of blood flow causes claudication, a cramping-like pain that only gets better with rest[1,2]. Ankle assistive devices have recently been implemented in various clinical populations to improve walking ability. Our group has developed an ankle assistive device to improve walking ability in patients with PAD. However, before implementing the device in patients, it is necessary to identify the appropriate design criteria that would benefit the patient most. This study tested the effect of our newly developed assistive device on metabolic costs across several tension assistance levels.

METHODOLOGY

Ten young healthy subjects (age: 22.7 ± 1.64 years, BMI: 22.32 ± 2.38 kg/m^2) were recruited for this study. The experiment was initiated with a quiet standing trial lasting five minutes. After the quiet standing trial, subjects walked on an instrumented treadmill (AMTI, Watertown, MA) for five minutes while metabolic data was recorded using a portable metabolic cart (Parvo Medics, Sandy, UT). Metabolic cost was determined as the mean VO2 in the final two minutes of the walking trials. The VO2 data was normalized to body mass for between subject comparison. The net cost of walking for each subject was determined by subtracting the subject's quiet standing metabolic cost from the metabolic cost of the walking trials. Each subject repeated the test for a total of 4 conditions: normal walking without the device (NORM) and walking with three different tension assistance levels. Different tension assistance levels were achieved by changing the spring stiffness (light, medium, and stiff). Paired t-tests were conducted to determine the significance between NORM and different tension assistances ($p < 0.05$, SPSS Version 26, IBM, Armonk, NY).

RESULTS AND DISCUSSION

Our results showed that there were no significant changes in metabolic cost when changing the tension assistance levels compared to NORM. The light and medium tension assistance reduced the average metabolic cost by 0.0096 ml/kg/min ($p < 0.609$) and 0.0255 ml/kg/min ($p < 0.0803$) respectively from normal walking (Figure 1, Table 1). However, changing the tension assistance to stiff increased the average metabolic cost by 0.6494 ml/kg/min ($p < 0.388$) (Figure 1, Table 1). This result suggests that a cut-off spring stiffness exists between the medium and stiff stiffnesses that may correspond to a minimum reduction in metabolic cost. The spring stiffnesses for this study were chosen arbitrarily. Future studies should include a greater number of spring stiffness and more subjects to establish a more robust relationship between the metabolic cost and tension assistance level.

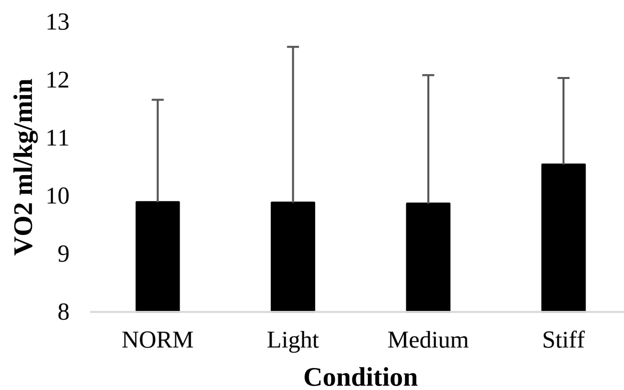

Figure 1: The net metabolic cost of walking for the normal walking condition (NORM), the light spring stiffness, the medium spring stiffness, and the stiff spring stiffness.

ACKNOWLEDGEMENTS

This study was supported by UNO FUSE grant and NIH grants (R01AG034995 and R01HD090333).

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Table 1: Metabolic cost of walking without assistance (NORM) and with three different tension assistances (light, medium, stiff).

	NORM ml/kg/min	Light (ml/kg/min)	Medium (ml/kg/min)	Stiff (ml/kg/min)
Average	9.8943	9.8847	9.8688	10.5437
Standard Deviation	1.7655	2.6884	2.2163	1.4920

CHANGES IN THE BIOMECHANICS OF HUMAN AORTAS AND FEMOROPOPLITEAL ARTERIES WITH AGE

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Presentation Preference: **Podium**

INTRODUCTION

Arterial mechanical and structural characteristics play important roles in physiology and pathophysiology and profoundly influence the design of devices for open and endovascular repair. The two main types of arteries are elastic and muscular. Elastic arteries are larger and are located closer to the heart. They contain a substantial amount of elastin that allows them to act as a buffering chamber behind the heart, storing the elastic energy during peak systole and returning it during diastole when the heart rests. Muscular arteries serve a different purpose. They deliver blood from the elastic arteries to the downstream tissues and organs and regulate the amount of that delivery by relaxing and contracting concentric layers of smooth muscle cells. We hypothesized that functional and structural differences in elastic and muscular arteries result in different mechanical properties and adaptation to aging. To test this hypothesis, we have compared human descending thoracic aortas (TA) and superficial femoral arteries (SFA) from the same donors using planar biaxial mechanical testing, histological analysis, and constitutive modeling.

METHODS

Descending TAs and SFAs were obtained from 26 tissue donors 13-73 years old (average 41±18 years, 80% male). Prior to the excision of the SFAs, their longitudinal pre-stretch was measured, and the pre-stretch of the TAs was estimated using previously published data. Arterial diameters and opening angles were measured optically, and the mechanical properties were assessed using planar biaxial testing. These data were then used to determine constitutive parameters for the four-fiber family invariant-based model previously shown to accurately portray the behavior of both elastic and muscular human arteries[1,2]. Morphometric and mechanical data were further used to calculate the physiologic stress-stretch state, and the structural evaluation of collagen and elastin was done using two-dimensional histology.

RESULTS AND DISCUSSION

Both the TA and the SFA increased their thickness and diameter with age, but the TA thickened and widened faster than the SFA. The circumferential opening angle was similar in younger and older TAs (279±51°) but increased in the SFAs from 95° to 227°. Longitudinal pre-stretch decreased with age in both arteries. In the TA, it decreased from 1.4 to 1.05 and in the SFA from 1.6 to 1.2. Young TAs were relatively isotropic, but after 40 years of age, the anisotropy increased, and the tissues became stiffer longitudinally than circumferentially. In contrast, young SFAs were more compliant longitudinally than circumferentially but became more isotropic with age as the longitudinal direction stiffened faster than the circumferential. In both arteries, the circumferential and longitudinal physiologic stresses decreased with age. The circumferential decrease was 10% in both arteries, while the decrease in the longitudinal direction was more significant for the SFA than for the TA. During the cardiac cycle, young TAs experienced 1.16 circumferential stretch, while old aortas stretched only 1.04. In contrast, young SFAs changed their diameter only 3% over the cardiac cycle, and this value dropped to 1% in older SFAs. The elastic energy available for pulsation was much higher in young TAs (12.6 kPa) than in the SFAs (1.4 kPa), and as both arteries stiffened with age, the elastic reserve diminished but remained larger in the TA (5.1 kPa) than in the SFA (0.7 kPa). Both the SFA and the TA demonstrated more fragmented elastic fibers and lamellae and higher medial collagen content in older specimens.

CONCLUSIONS

Functional and structural differences in elastic and muscular arteries resulted in different mechanical properties and adaptation to aging. Elastic TAs had a greater capacity for pulsation over the cardiac cycle than the SFAs. In contrast, the muscular SFAs had higher longitudinal pre-stretch (and the associated stress), which may help them accommodate deformations during end-organ motion. Aging was associated with stiffening of both arteries, but the degree and direction of stiffening were different in elastic and muscular arteries. These data can be used to gain a better understanding of arterial physiology and pathophysiology and may guide the design of materials and devices for aortic and lower extremity repairs.

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COMPARISON OF FOOT TEMPERATURE RESPONSES AFTER WALKING ON OVERGROUND VERSUS TREADMILL

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Presentation Preference: [**Poster**]

INTRODUCTION

The foot is an important part of the body to investigate thermoregulatory dynamics in healthy human subjects. Because the foot is in constant contact with the ground during walking, studying its interaction with different surfaces could prove useful for accurate temperature data collection in humans [1,2]. Previous studies have found that walking barefoot on a treadmill caused significant differences in plantar surface temperature at four different sites on the foot [3]. However, it is unclear whether heat was due to the mechanical work done by the foot structures or due to the friction caused by the treadmill belt. In the latter case, according to thermodynamic principles, heat may be transferred from the treadmill to the foot, increasing the foot's temperature. The aim of this study is to compare foot temperature profiles after barefoot walking on a treadmill versus overground. We hypothesized that walking barefoot on a treadmill will increase the temperature of the bottom of the foot more than walking barefoot overground.

METHODS

9 participants followed similar procedures done in a previous study [3]. This study design included 4 ten-minute walking trials with 2 different added mass conditions across 2 different surfaces treadmill and track. Walking speed was controlled at 1.25 m/s on both surfaces, where overground walking speed was controlled by having the participant follow a designated pacer. Participants walked with 2 added mass conditions: first, at 0% extra added body mass (no weighted vest) and second, at 30% extra added body mass (with a weighted vest). The 4 ten-minute walking trials were randomized and separated into 2 trials of treadmill walking and 2 trials of overground walking on an indoor track. Pre- and post-walking temperature data of each foot's plantar surface were collected by using a FLIR Thermal Imaging Camera (FLIR Systems, Wilsonville, Oregon) and Contact Probes (Extech Instruments, Nashua, New Hampshire). At the beginning of each walking trial, participants were transported to the designated starting point while sitting in a wheelchair with their feet raised to avoid any unnecessary heat transfer. After treadmill walking, participants were transported back to the bench via wheelchair. However, after overground walking, participants walked back to the bench (the time taken to walk towards the bench was included in the ten-minute trial). Participants rested lying supine on the bench before and after walking for 30 minutes to collect plantar surface temperature data and to cool down the foot to near baseline temperatures before proceeding to the next trial.

T-tests were used to compare pre- and post-walking temperature values with significance at 0.05. The same test was used to compare pre- and post-walking temperature changes between different conditions.

RESULTS AND DISCUSSION

Pre- and post-treadmill walking plantar surface temperatures were consistent with the results found in previous work [3]. Comparing pre- and post-walking foot temperatures,the foot temperature increase was significantly greater on the treadmill compared to overground, including during both 0% added mass ($p<0.001$) and 30% added mass ($p<0.001$).

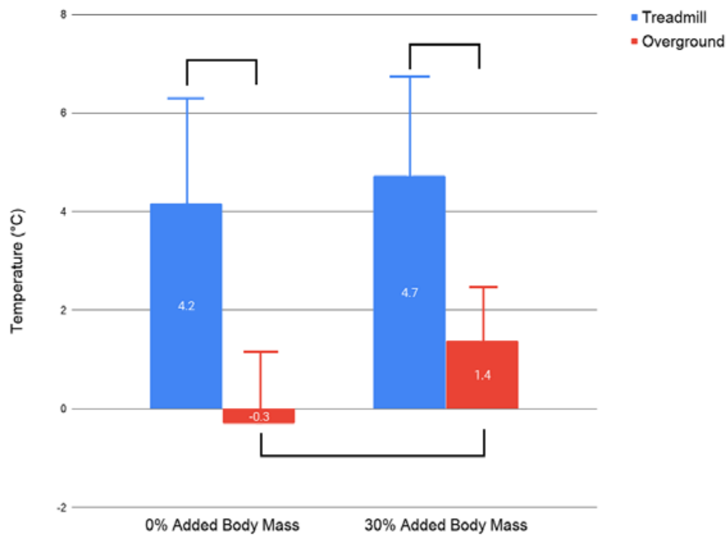

Figure 1: Change in Whole Plantar Surface Temperature in Track and Treadmill Conditions. A comparison of changes in all 4 walking conditions. Square brackets indicate significant differences.

CONCLUSIONS

Our results suggest that the foot temperature response is influenced by the surface of the floor. With that in mind, overground surface should be used to capture true and accurate foot temperature measurements while barefoot walking.

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MARGIN OF STABILITY IS LARGER AND LESS VARIABLE DURING TREADMILL WALKING VERSUS OVERGROUND

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INTRODUCTION

To maintain stability during walking, the body's center of mass (COM) must be controlled effectively within the base of support provided by the feet. In general, margin of stability (MOS) is defined as the distance between the extrapolated COM (i.e. a point on the floor at a distance from the COM that is directly proportional to the COM velocity) with respect to the limits of the base of support during walking in the anterior posterior (AP) and mediolateral (ML) directions [1, 2]. Decreased dynamic stability can be described by decreasing the mean and/or increasing the variability of MOS. During unperturbed walking conditions, dynamics of stepping are expected to result in a similar trend of stability outcomes during walking at different speeds either overground or on a treadmill. However, conflicting MOS results during unperturbed treadmill versus overground situations have been reported [2]. The aim of this study is to determine if walking on a treadmill vs. overground will affect MOS at heel contact during three, speed-matched conditions.

METHODS

Twelve healthy young participants, (24.8±5.1 years; 73.0 ±11.8 kg; 1.74±0.07 m) without any disorders that would cause abnormal gait control were recruited to this study. Participants walked on an instrumented treadmill and overground at slow, preferred, and fast speed-matched conditions, while kinematic (marker) data were collected. Four participants' data could not be included in the analysis due to insufficient speed-matched steps across modes of walking.

The mean and variability (standard deviation) of the MOS in AP and ML directions at heel contact were calculated for 18 right and left steps during overground and treadmill trials. Moderate to strongly correlated (r>0.30) spatiotemporal variables to stability margins (consistent between conditions) were included as covariates. To identify the main effect of walking conditions (treadmill vs. overground) and speed conditions (slow, preferred, fast), and the possible interaction between condition and speed, generalized estimating equations were used. The significance threshold was $\alpha=0.05$.

RESULTS & DISCUSSION

After controlling for the step velocity as a covariate for MOS AP mean, there were no significant main effects or interaction for MOS AP mean. There was a significant interaction between speed and walking condition ($p<0.0001$) for MOS AP variability, without considering a consistent covariate in the model (Figure 1). Faster speed was more variable than preferred and slow during overground, while there was not a significant difference during treadmill between fast and other two conditions. Increased stride length variability during overground compared to treadmill [5] could be a potential factor for increasing the variations of foot placements and consequently MOS in the sagittal plane during faster speeds which are more physically demanding. Slow walking was more variable in AP direction compared to preferred during treadmill, suggesting a different mechanism on treadmill versus overground.

After controlling for step width as a covariate for MOS ML mean, MOS ML during fast and preferred was significantly smaller compared to slow (adjusted p's < 0.001), which might be in regards to maintenance of frontal plane stability in the presence of more challenges to the motor control system during slow, leading to lack of stability. MOS ML during treadmill walking was larger than overground ($p=0.003$). Subjects may try to increase lateral stability by voluntarily increasing base of support via control of foot placement on treadmill. Without considering a covariate, a significant interaction for MOS ML variability was found; however, no significant pairwise comparisons were found upon post hoc analysis.

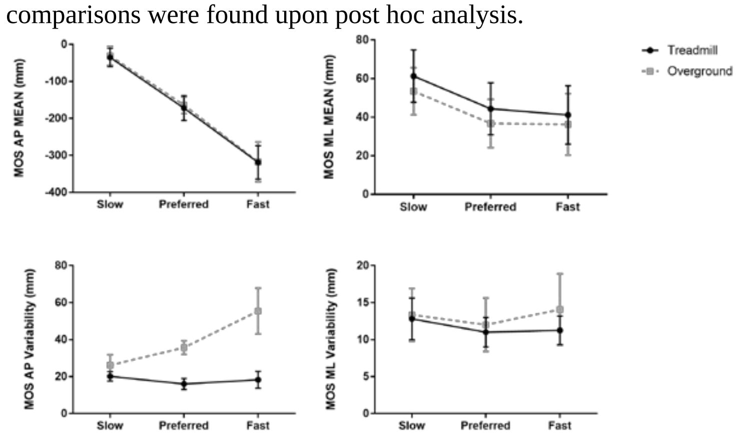

Figure 1: MOS mean and variability values in AP and ML directions.

CONCLUSIONS

MOS ML means were larger during treadmill walking compared to overground and decreased as participants walked faster. In the absence of natural optic flow during treadmill walking, as well as different proprioceptive input (legs being pulled back during treadmill while remain stationary during overground), subjects may employ strategies to increase stability. Greater variability of MOS AP during faster speeds may have been the result of more natural fluctuations during overground walking while on the treadmill variability remained consistent due to a more repetitive pattern of stepping.

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DEVELOPMENT OF A COMPREHENSIVE PITCHING EVALUATION TO ASSESS INJURY RISK IN COLLEGIATE BASEBALL PITCHERS

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Presentation Preference: **Poster**

INTRODUCTION

Every year, approximately three million children play baseball in the United States, with an additional 25,000 competing in the National Collegiate Association of America (NCAA) [1,2]. Furthermore, 40% of NCAA baseball players will be injured at some point during the season [3]. The pitching motion is a complex blend of segmental interactions that create a kinematic and kinetic chain up the body, leading to transfer of momentum to the baseball [4]. Key indicators within the throwing motion allow us to monitor player mechanics and improve deficiencies when they are present. Quantitative data from these key indicators help monitor pitcher performance to screen for signs of kinetic and kinematic deficiencies. The goal of this study is to examine the efficacy of biomechanical evaluations on collegiate pitchers. Through this, we will seek to develop a model for identifying at-risk athletes through a longitudinal assessment of pitching mechanics spanning pre-season to post-season along with in-season tracking of pathomechanics.

METHODS

Thirteen student-athletes from the UNO men's baseball team were included for the pilot evaluation. Pitchers underwent a two-part evaluation, starting with clinical measurements. Shoulder range of motion (RoM) was measured as players lied supine with the arm positioned at 90° of both shoulder abduction and elbow flexion. Once positioned, an inclinometer was placed on the distal forearm, proximal to the wrist while the arm is in shoulder external and internal rotation. A paired t-test was used to determine statistical significance between RoM values.

For the biomechanics evaluation, players were outfitted with a full body reflective marker set before the acclimation and warm-up throwing session. Once ready, the pitcher was instructed to throw from an indoor, force-plate instrumented mound to a catcher 60.6' away, conforming to NCAA baseball regulations. Professional grade motion-capture cameras (Qualisys, Gothenburg, Sweden) were mounted on tripods placed symmetrically around the pitching mound to capture the players motion via Qualisys Track Manager software. Sampling frequency of the cameras was set to 240 Hz. Key biomechanics variables were calculated using Visual 3D (C-Motion Inc., Rockville, MD) software. Upon completion of the biomechanics evaluation, risk factors for injury were documented on a specialized report. A group of movement specialists then created a thorough analysis of the data to develop customized training programs targeted at individual needs of the athlete.

RESULTS AND DISCUSSION

Preliminary results obtained from the pilot evaluation demonstrate that movements too low or high of normative values for key biomechanical indicators were found within our assessment measures. RoM inefficiencies include a >20° deficit in total RoM between arms (Table 1).

Table 1: External and internal shoulder range of motion of Athlete 1

	Left (Non-throwing)	*Right (Throwing)*
Internal Rotation	55°	31.5°
External Rotation	70.5°	86.8°
Total RoM	125.5°	118.3°

Movement inefficiencies were identified in four out of eleven key categories in one athlete and four of eleven in another athlete. The most noticeable inefficiency observed in both athletes was the timing of peak velocity in the kinematic sequence (Figure 1). It was determined that both athletes' throwing hands reached peak angular velocity before their throwing arm, indicating that the ground-up aspect of the kinetic chain was not conducive to energy transfer. To correct for this and other noticeable biomechanical errors, each athlete was given a set of exercises to aid in establishing proper movement patterns such as overhead medicine ball throws to establish lead-leg extension.

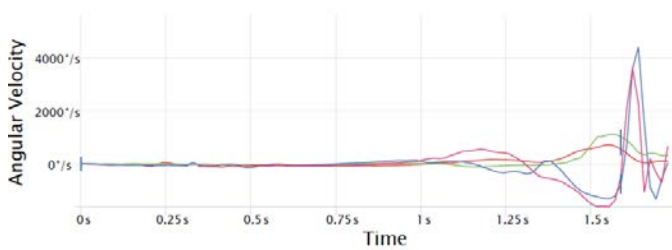

Figure 1. Kinematic sequencing chart taken from a biomechanical report generated from the motion capture evaluation

CONCLUSIONS

The ability of a comprehensive pitching evaluation demonstrates the ability to identify biomechanical inefficiencies to aid in assessing injury risk in collegiate baseball players. Biomechanical inefficiencies were observed in each athlete tested. Further pitching evaluations will be conducted to observe the longitudinal impact on injury prevention.

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SHOULD SPORT TECHNIQUE CONFORM TO A CRITERION OPTIMAL TECHNIQUE? AN ANALYSIS OF SPIKE TECHNIQUE IN VOLLEYBALL OF TWO HIGH-LEVEL ATHLETES

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Presentation Preference: **Poster**

INTRODUCTION

The role of sport biomechanics serves in part to enhance performance through the optimization of technical movement skills. Typical sport biomechanics research tends to analyze group data to identify key kinematic characteristics of a movement pattern that are indicative of performance [1]. Doing so establishes a criterion "optimal" movement pattern which sets the standard to be achieved in order to be successful. However, this approach creates a bias to group averages and fails to capture the importance of individuality to the human movement system. A criterion benchmark from averaged group data may not be applicable to specific athletes [1].

The volleyball spike may best be modeled as a quasi-whip-like motion where distal hand speed is maximized by coordinating the body for the sequential transfer of energy from proximal-to-distal segments [2]. A large trunk rotation angle is often viewed as a key performance indicator to successful spike performance, as this will utilize the stretch shortening cycle to create a more forceful initiation of the spike [2].

With the question of criterion benchmarks in mind, the present study investigates whether spike technique of two high-level women's volleyball players conforms to an ideal technique.

METHODS

Spike mechanics were assessed for two outside hitters on a division 1 collegiate women's volleyball team. The athletes performed 10 power spikes in a laboratory while full-body kinematic data was recorded at 300 Hz (Qualisys, Göteborg, Sweden). In order to maximize the ecological design of data collection, a net was set up to a regulation height of 2.24 m and a setter set the ball to the athletes. A traffic cone was placed on the opposite side of the net as a target for the subject to attack. Instruction was provided to the athletes to maximize ball speed and accuracy. Only accurate attacks were selected for analysis.

Upper extremity and trunk joint angles were calculated using Visual 3D (C-Motion, Germantown, Maryland). Coordination between trunk rotation, shoulder rotation, and elbow extension was analyzed using cross correlations. Hand speed was calculated as a performance outcome. Coordination and performance was compared between the two athletes.

RESULTS AND DISCUSSION

Both athletes obtained similar peak hand speed during the spike. Athlete B was able to obtain a greater trunk rotation angle, while athlete A obtained a greater shoulder rotation angle. The athletes displayed different coordination strategies as can be seen in Figure 1.

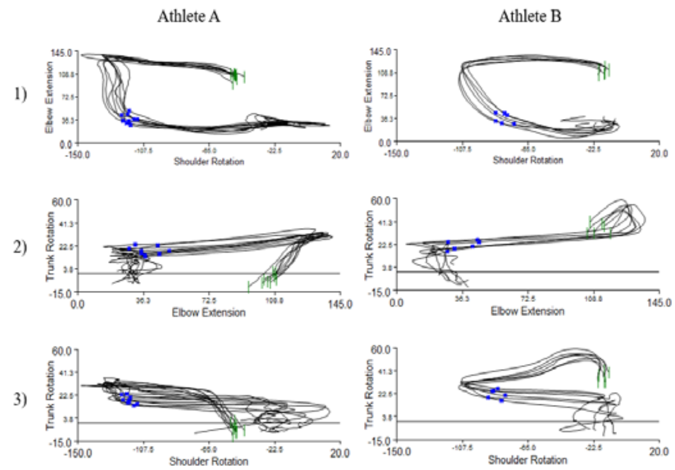

Figure 1: Angle-angle plots for each athlete. 1, Elbow Extension-Shoulder Rotation; 2, Trunk Rotation-Elbow Extension; 3, Trunk Rotation-Shoulder Rotation. Green tick = event of arm cocking. Blue cross = event of contact.

The present data show two athletes who achieve similar hand speeds, but do so with differing technique. Athlete B likely produces a more forceful contraction at the trunk due to greater trunk rotation angle. Athlete A likely relies more so upon her shoulder and elbow due to the greater shoulder rotation angle.

In order to optimize athlete A, should coaches modify her technique to create a greater trunk rotation angle? The individual constraints of this athlete (anthropometric, inertial, strength, and viscoelastic properties of her musculature, etc.) may not be suited to create a large trunk separation angle. Since she can perform at a high level with her current technique, modifying an aspect like trunk rotation may in fact improve performance, but it may also result in reduced performance.

CONCLUSIONS

The present data show two high-level volleyball athletes, who display very different strategies in executing the spike technique. Despite the common notion that trunk rotation is crucial for spike performance, more may not always be better. Athletes' technique should be analyzed as individuals. Understanding the capabilities and anatomical constraints of an athlete may allow coaches to judge when to modify technique.

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Roll-over shape is preserved while walking with and without claudication pain in patients with peripheral artery disease

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Presentation Preference: [**Podium**]

INTRODUCTION

Peripheral artery disease (PAD) is caused by atherosclerosis in the peripheral arteries that obstructs blood flow of around 8-12 million people in the United States alone [1]. PAD causes claudication pain and early fatigue, which makes walking difficult and leads to a sedentary life in such patients. Presently, orthosis/ exoskeletons are being developed to help patients with PAD walk more or with less pain. Roll-over shape (ROS) is a potential design goal for such assistive devices. ROS is the effective rocker generated by the ankle-foot complex during the single limb stance phase of walking [2]. ROS is invariant to walking speed, carrying additional weight and wearing different types of footwear [2]. This invariance of ROS makes it an appropriate design goal for lower limb prosthetic and orthotic devices to mimic normal walking. The goal of this work is to investigate ROS characteristics in patients with PAD during pain-free and painful overground walking.

METHODS

The gait data of ten patients with PAD (Age 63.2±4.8 years) from a previously IRB approved study was analyzed to calculate ROS parameters. Gait data was recorded using eight-camera 3D motion capture system while the subject walked along 10 m walkway at self-selected walking speed. The center of pressure (CoP) data was collected using a force platform embedded in the ground. Three gait trials with clean force plate strikes for the most affected leg during pain-free and painful overground walking were used. The leg with higher ankle-brachial index was considered as the most affected.

The ankle-foot ROS was generated by transforming CoP data from the ground fixed coordinate system to the shank-based coordinate system. These transformed CoP data points were fit with a circular arc to characterize the ROS using parameters such as radius and arc length. The MATLAB™ based optimization algorithm was used to find the best fitting circular arc. Height normalized; average ROS parameters were calculated for each subject. Paired t-tests were used to determine the significant differences (p<0.05) between the two walking conditions for roll-over radius and arc length.

RESULTS AND DISCUSSION

The ROS in a representative patient with PAD along with its parameters is shown in Figure 1. The mean ROS parameters during pain-free and pain walking are shown in Figure 2. Statistical analysis showed that the mean roll-over radius (p=0.819) and mean arc length (p=0.626) parameters were not significantly different between the pain-free and pain walking conditions. Our preliminary results show that the ROS is preserved even during claudication pain in patients with PAD. This finding corroborates with the general invariance model of ROS during different walking conditions in healthy individuals [2,3].

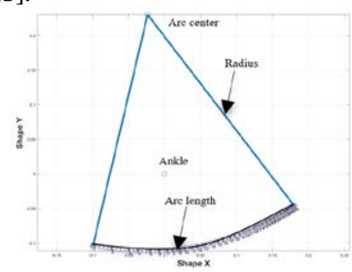

Figure 1: Roll-over shape in a representative patient with PAD.

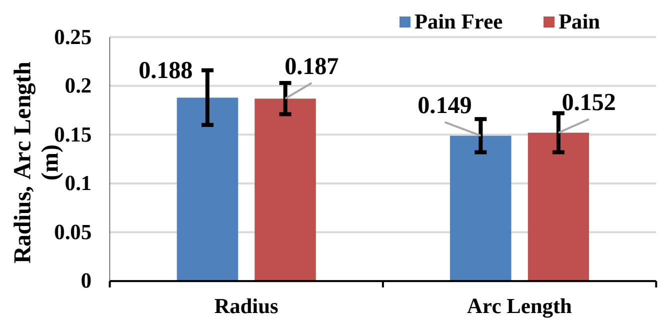

Figure 2: Comparison of roll-over radius and arc length during pain-free and pain walking in patients with PAD.

CONCLUSIONS

Roll-over shape remains invariant before and after the onset of claudication pain in patients with PAD. This finding validates the use of ROS as a potential design goal for the assistive devices that are under development for patients with PAD.

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THE EFFECT OF SEASON AND PRECIPITATION ON PHYSICAL ACTIVITY AMOUNT, STRUCTURE, AND COMPLEXITY IN STROKE SURVIVORS

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INTRODUCTION

Stroke survivors are less active than healthy age-matched individuals[1]. Physical activity is tied to many serious health issues[1], so it is important to fully understand the way stroke survivors move to target the most effective rehabilitation strategy. Stroke survivors report that unfavorable weather is discouraging to activity, especially where precipitation increases the risk of falling[2]. Nonlinear analyses can incorporate analysis of quantity, structure, and complexity of physical activity. Jensen-Shannon Divergence (JSD) describes data with a measure of divergence from the data's probability distribution[3]. Lempel-Ziv Complexity (LZC) is a nonlinear measure that analyzes sequences of data and their occurrences as patterns[4]. The objective of this study was to examine physical activity patterns after stroke. We will explore the relationship between weather and stroke survivor step counts, and their activity structure and complexity as measured by JSD and LZC, respectively.

METHODS

Six days of physical activity data for 142 subjects were analyzed as a part of a University of Delaware clinical trial (NCT02835313). Step counts were recorded every minute from a Fitbit worn on the less-affected ankle[5]. Data was analyzed using custom MATLAB code (MathWorks, Natick, MA). Measures included total and mean daily steps, JSD values (how regular each individual's activity was across days), and LZC values (how complex their activity was based on patterned changes between different levels of activity). Seasons were defined by three-month periods based on winter as December through February. Weather data from the Philadelphia Mt. Holly Weather Forecast Office was used to analyze activity data based on the presence of precipitation on individual days. One-way ANOVAs were used for all analyses. Relationships with $p<0.05$ and $r^2>0.49$ were considered significant.

RESULTS AND DISCUSSION

A one-way ANOVA found a significant effect on LZC values by season (Figure 1C) with spring LZC values greater than winter LZC values as determined by a Tukey test ($p=0.019$). All other comparisons were insignificant ($p>0.05$). Activity was more complex during spring than during winter when activity may be restricted due to weather. This finding indicates that targeting a rehabilitation plan that incorporates tasks with a variety of durations and intensities, as to increase complexity, may help increase activity levels in stroke survivors more effectively than a goal to increase an overall daily step count, especially during times of unfavorable weather conditions.

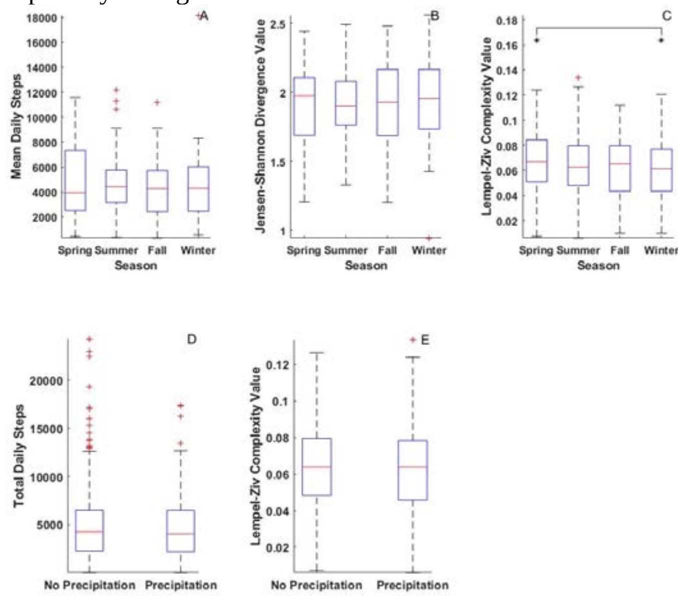

Figure 1: The effect of weather on linear and nonlinear physical activity measures. Figures 1A, 1B, and 1C show the effect of season on mean daily steps (n=142) JSD values (n=142), and daily LZC values (n=852), respectively. Figures 1D and 1E show the effect of precipitation on total daily steps (n=852) and daily LZC values (n=852), respectively. Significant between-group comparisons are denoted with asterisks connected by brackets.

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R01 HD086362

THE EFFECT OF A 6-WEEK SIDEWAYS WALKING INTERVENTION ON GAIT BIOMECHANICS IN COMMUNITY-DWELLING OLDER ADULTS

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Presentation Preference: [**Poster**]

INTRODUCTION

One-third of older adults aged 65+ are susceptible to falling, mostly during walking [1]. We propose that older adults with age-related gait abnormalities can improve walking patterns by performing sideways walking training.

METHODS

Fourteen older adults aged 65+ (3m; age: 70 ± 3 yrs.; height: 166.1 ± 10.9 cm; mass: 72.6 ± 12.6 kg) were recruited for this study. Inclusion criteria were (i) ≥ 65 years, (ii) be independently residing in the community, and (iii) ability to walk independently. Participants were not eligible if they (i) had neurological disorder or progressive neurologic condition, (ii) had a musculoskeletal disorder or injury that could affect gait, (iii) had surgery within the past 6 months, (iv) had history of cardiovascular event, and (v) were participating in any other interventional trial that involves walking, balance or exercise training.

Data were collected at the Biomechanics Research Building facility at baseline, postintervention, and retention period (6-week following completion of the intervention), from November 2017 to September 2018. The facility featured a 3D motion capture system with 17 high-speed Raptor cameras (Motion Analysis Corporation, Santa Rosa, CA, USA) synchronized with 8 imbedded force plates (AMTI, Watertown, MA). Upon arrival at the Biomechanics Research Building for the baseline assessment, the participants changed into a tight-fitting suit. Then, retroreflective markers were placed at anatomical locations to gather three-dimensional kinematics (sampling rate @100Hz) and dynamics data (sampling rate @1000Hz) during sideways walking. Retroreflective markers were placed to anatomical landmarks to define a fifteen-segment (left and right: foot, shank, thigh, forearms, upper-arms, and pelvis, trunk, head) mechanical model of the human body. In addition, clusters of rigid reflective tracking markers were placed on the lateral surfaces of each participant's thigh and shank segment. After obtaining a static calibration trial, only the clusters and the tracking markers left on.

The participants performed 10 trials of sideways walking on a 10 m walkway on their preferred speed. The three-dimensional net forces and moments at the right and left ankle, knee and hip joints were estimated by solving the dynamical equations of a free body diagram. Inverse dynamics computations were carried out using the Visual3D software (Germantown, Maryland, US). The three-dimensional coordinates of the digitized markers, ground reaction forces, and center of pressure, were smoothed with quintic splines according to the "Generalized, Cross-Validation" criterion [2]. Center of mass locations, masses, and moments of inertia were estimated using a gender-dependent anthropometric model [3]. For comparisons, the results were normalized by subjects' body mass, while time was expressed as percentage of total gait cycle duration.

Following baseline assessment, the participants 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 stepped laterally across a 10m section on an indoor track, changing direction at the ends thus alternating lead and lag legs. Three minutes of lateral stepping was alternated with at least one minute of rest. They informed that they could increase their pace at the start of each session but may not decrease it at the next session. This promoted continued learning and prevent any plateau effect. Similar to the baseline assessment, three-dimensional kinetics data were collected after completion (post) of the training, and six-weeks following completion (retention). Self-selected speeds were used for all trials at each assessment.

RESULTS AND DISCUSSION

Sideways walking training can significantly affect the mechanical characteristics of gait in older adults. This has implications for walking balance training in older adults, which could be directed to exploit the mechanical features of gait dynamics, such as motion-dependent torques, which are not sensitive to age-related deficiencies of active control or the lack thereof.

CONCLUSIONS

Our 6-week sideways walking is a potential exercise intervention to improve walking patterns in community-dwelling older adults.

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PATIENTS WALK LESS EFFICIENTLY FOLLOWING REVASCULARIZATION

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Presentation Preference: [Please indicate (1) **Podium preference, Student**]

INTRODUCTION

Peripheral artery disease (PAD) is a cardiovascular disease that manifests from atherosclerotic blockages in the extremities. Lower extremity PAD results in intermittent claudication, a debilitating leg pain caused by insufficient blood flow to the lower-limb muscles during physical activity. PAD severely impacts patients' ability to complete daily living tasks thereby negatively affecting their independence and quality of life. A key functional limitation caused by PAD is reduced ankle power during late stance compared to healthy, aged-matched adults [1]. Previous literature suggests that this reduced ankle power during late stance could correlate to an increase in negative work during early stance [2]. Work is the amount of energy expended over time with a unit definition of joules. Positive work contributes towards propulsion, while negative work slows forward progression. We hypothesized that revascularization to restore blood flow to the affected lower-limbs would lead to improved walking mechanics as demonstrated by increased walking efficiency. Walking efficiency will be defined as a percentage of positive work of the absolute total work throughout the stance phase of gait.

METHODS

Thirty-seven subjects with PAD were recruited by the Nebraska-Western Iowa Veterans' Affairs Health Care System. Subjects completed over-ground walking trials at self-selected speed before and 6-months following revascularization surgery. Subjects walked over eight in-ground AMTI force plates until six quality foot-to-force plate contacts were recorded for each leg. Three-dimensional kinematics were collected using 17 motion capture cameras (Cortex 5.1, Motion Analysis Corp, Santa Rosa, CA) with retro-reflective markers placed at specific anatomical locations according to a modified Helen Hayes marker set [3].

Lower-limb joint powers were calculated from heel contact to toe-off using Visual3D (Visual3D, Germantown, MD, USA). Joint work was calculated as the integral of joint power utilizing MATLAB 2018a. Ankle, knee, and hip work was normalized to percent of stance and divided into three phases: early (0-28%), middle (29-74%), and late (75-100%). Work at all joints was summed for each phase. Paired t-tests were used to test for significance of summed joint work at each phase with a Bonferroni corrected α-level of 0.05.

RESULTS AND DISCUSSION

Contrary to our hypothesis, patients with PAD produced more negative work during early stance and less positive work during late stance following surgery ($P<0.01$). This suggests that patients with PAD walk less efficiently following surgery. Figure 1 shows a 10% relative increase in negative work compared to absolute total work during early stance. These findings may be attributed to the surgery's required recovery time. Operative wound healing following open revascularization surgery requires 1.9 months on average [4]. This period of increased rest in an already sedentary population could negatively affect patients' walking gait efficiency. Inefficient walking gait could correlate to reduced physical activity overall and therefore, is important to address for improved patient outcomes. These findings suggest the need for a more elaborate rehabilitation strategy following surgery to improve or maintain walking gait efficiencies.

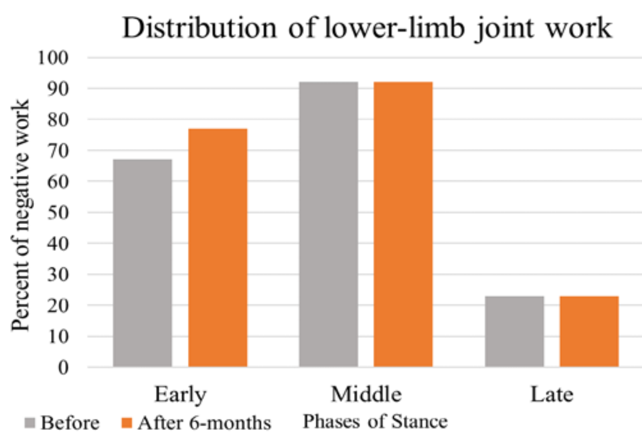

Figure 1: Summed lower limb joint work performed by patients with PAD before and 6-months following revascularization surgery. Grey and orange bars represent negative work as a percent of total work performed during each phase of stance.

CONCLUSIONS

Revascularization surgery decreased walking gait efficiency in patients with PAD and may be attributable to the needed recovery time following the procedure. Future studies warrant investigation into the potential benefit of rehabilitation or assistive devices to improve walking gait mechanics in patients.

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THE EFFECT OF CHANGING STIFFNESS IN A SHOCK-ABSORBING PYLON ON PROSTHESIS MECHANICAL WORK

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INTRODUCTION

Walking with a shock-absorbing pylon (SAP), as opposed to the traditional, rigid pylon, increased comfort and reduced residual limb pain for lower limb prosthesis users [1]. This is done via a spring inside the pylon which changes the overall longitudinal stiffness of the prosthesis. Thus, the function of SAPs are to attenuate forces upon impact (i.e., dissipate shock to the residual limb) [1,2]. Previous gait studies with SAPs found significant differences in peak magnitude of ground reaction forces [1,2]. The applied forces (i.e., ground reaction forces) can determine the amount of energy a spring can store and release, and as a consequence, influence the mechanical work done by the prosthetic limb during walking [3]. However, it is unclear how the effect of a SAP's longitudinal spring stiffness affects the mechanical work done from a joint-level perspective (i.e., by the prosthesis, knee, and hip joints). The purpose of this study was to investigate the effects of spring stiffness and walking speed on the mechanical work done by the prosthesis in individuals with unilateral transtibial amputation (TTA). We hypothesized that: (1) a more compliant spring will result in greater negative work during early stance, and subsequently produce greater positive work in later stance (i.e., greater energy stored and returned) and (2) faster walking speed will amplify the effects of spring stiffness on mechanical work as ground reaction forces increase.

METHODS

A secondary analysis was performed on 12 participants with unilateral TTA from a previous study [2] (4F/8M; age: 48.9±17.9yrs; height: 1.80±0.10m; mass: 84.8±21.0kg; Participants walked overground at their self-selected walking speeds, customary/typical (1.22±0.01m/s) and fast (1.53±0.01m/s), over four SAP spring conditions of increasing stiffness: SOFT (75% of NORM), MED (50% of NORM), NORM (manufacture-recommended), and RIGID (steel cylinder). Power and work per stance were calculated from all prosthetic components distal to the socket ('prosthesis') using a unified deformable power analysis [4] and at the knee and hip joints using six degrees-of-freedom joint power [5] on at least three clean foot strikes and five strides per stiffness and speed condition. Total prosthetic limb power was estimated as the sum of the prosthesis, knee, and hip power. The stance phase was divided into four phases defined by the fluctuations of negative and positive work done by the total prosthetic limb: (1) collision (0-20% of stance), (2) rebound (20-54%), (3) preload (54-82%), and (4) push-off (82-100%) [6]. A two-way repeated measures ANOVA assessed the main and interaction effects of stiffness and speed on the positive and negative work of the prosthesis throughout stance and within each of the four phases in stance ($\alpha = 0.05$) (SPSS, IBM).

RESULTS AND DISCUSSION

No stiffness effect was found in positive and negative prosthesis work per stance ($p \geq 0.187$). However, within each of the four phases of stance, only the magnitude of negative collision work (i.e., during early stance) significantly increased as compliance increased ($p=0.045$) (Figure 1A-B). Therefore, our first hypothesis was partially supported. Speed effects were found as the magnitude of positive and negative prosthesis work per stance significantly increased with speed ($p<0.05$). Apart from the push-off phase ($p \geq 0.076$), the magnitude of negative collision, positive rebound, and negative preload work all increased with speed ($p<0.05$) (Figure 1B-E). Across all conditions per stance, the magnitude of negative work was greater than positive work (~13% of negative work), implying a damping effect that became more pronounced at faster speed. This net energy loss is most likely due to the prosthetic foot as the RIGID condition resembles a typical prosthesis with no SAP. No significant stiffness*speed interaction effect found in prosthesis work throughout stance ($p \geq 0.789$) and within each phase ($p \geq 0.391$). Therefore, our second hypothesis was not supported.

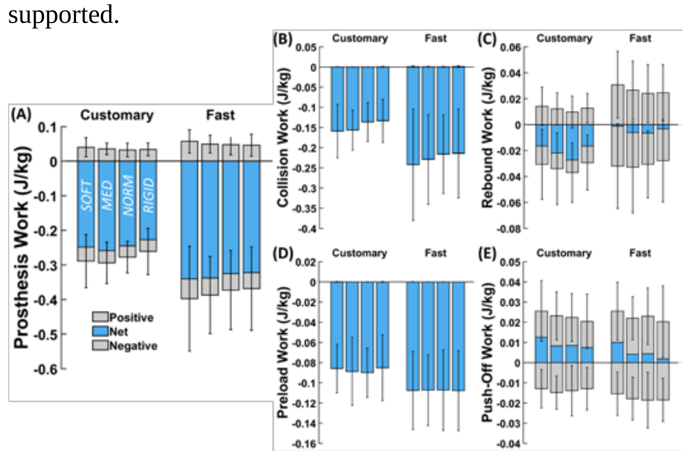

Figure 1: Mechanical work throughout stance (N=12) from the prosthesis (A) and within each phase of stance: collision (B), rebound (C), preload (D), and push-off (E).

CONCLUSIONS

A damping effect was seen from the prosthesis (large negative work, small positive work). While wearing SAPs on level ground walking may not be as effective, this pylon may be useful for activities requiring energy dissipation (e.g., downhill walking, gait termination, or traversing on uneven terrains).

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A Simulation-Based Investigation of Unbiased Detrended Fluctuation Analysis

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Presentation Preference: **Poster**

INTRODUCTION

Recent years have produced an ever-increasing interest in characterizing how human behavior changes over time. In part, this interest has been fueled by the observation that many biomechanical and physiological time series (e.g., stride time intervals, EEG) exhibit scale-invariant properties and long-range correlations. Unfortunately, time series methods like Detrended Fluctuation Analysis typically require a minimum of ~500 observations to obtain reasonable standard errors, which hampers efforts to understand temporal structure observed in human movement variability. The matter is further complicated in biomechanical studies that collect $\ll$ 500 observations per participant/trial due to limiting patient characteristics. We present a large simulation study of a method called Unbiased Detrended Fluctuation Analysis (UDFA) that was introduced to address these issues. We compare UDFA performance with the gold standard, Evenly Spaced Detrended Fluctuation Analysis (EDFA) and overlapping window version of DFA (ODFA).

METHODS

In this experiment, we replicate and extend work by Yuan et al.[1], comparing the performance of UDFA with ODFA and another method introduced to reduce bias in estimating α for short series, namely, EDFA[2]. To do so, we used Beran's [3] method to simulate a large number of time series that varied in terms of the scaling exponent, α, and the length of the time series, T. For each combination of α (0.1, 0.2, 0.3, …, 0.9) and T (64, 128, 256, …, 2,048), we performed UDFA and EDFA on 1,000 replicates in order to provide a rigorous comparison of their performance. These values were selected to represent a broad range of biomechanical and physiological time series data. In applying DFA, we sought to equate the three methods to the extent possible. For this reason, all methods resolved the same time scales, $s = 4$ to $T/3$, using a scaling factor of 1.2. Also, only a linear detrending function was used in all cases. All analyses were performed with custom C++ code, executed in R. UDFA and ODFA algorithms were based on original Matlab code shared by authors of Yuan et al.[1]

RESULTS AND DISCUSSION

Simulation results are depicted in Figures 1 through 3. Contrary to results reported in Yuan et al.[1], we find little support for the conclusions that (a) UDFA is unbiased or (b) that it outperforms ODFA. In fact, our results suggest that UDFA only outperforms the other methods in cases of strong negative autocorrelation. In all other cases, ODFA and EDFA tend to outperform UDFA. Moreover, ODFA and EDFA give similar performance to each other and tend to be positively biased. Bias direction depends on α in the case UFDFA. That is, UDFA overestimates when α is small but underestimates larger α.

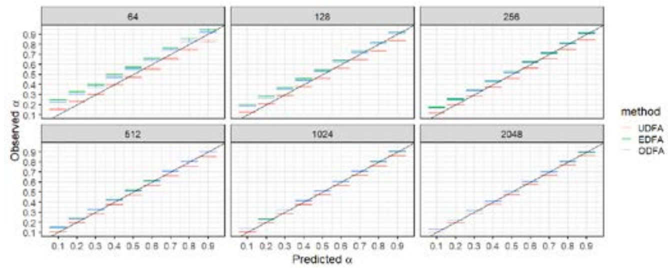

Figure 1: Observed α as a function of predicted α, T, and method. Diagonal line indicates optimality. Error bars represent 95% confidence intervals.

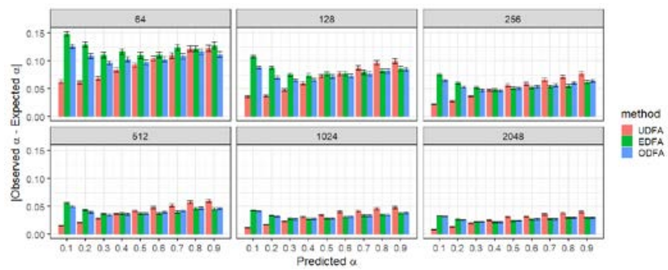

Figure 2: Average absolute deviation of α from expectation as a function of predicted α, T, and method.

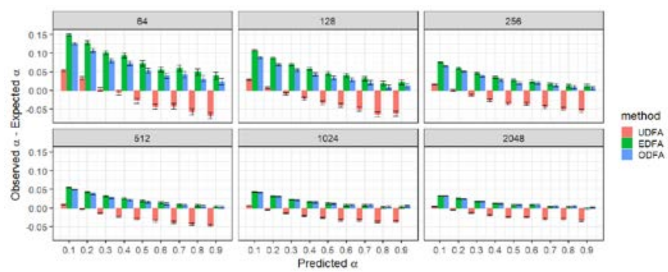

Figure 3: Average deviation of α from its predicted value as a function of predicted α, T, and method.

CONCLUSIONS

Results contradict those reported in Yuan et al.[1] In particular, our results suggest that ODFA and EDFA generally outperform UDFA, except in the case of strong negative autocorrelation. Differences in simulation methods should be explored in future work to understand this contradiction. Regardless, all methods generate systematic forms of bias and suggest possibilities to further reduce bias in the case of short series.

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ACKNOWLEDGEMENTS

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Autocorrelation and Probability Distributions in Gait-Metronome Synchronization

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Presentation Preference: Podium or Poster

INTRODUCTION

Recent studies have shown that the temporal structure of pacing signals (e.g., visual and auditory metronomes) influences the gait dynamics observed when coordinating with those signals [1,2]. Those studies typically involve pacing signals with interbeat intervals that are either constant over time or 'noisy', with the latter case referring to a class of signals that vary with respect to their autocorrelation function. To-date, however, no studies have directly examined the role that probability distribution functions play in gait-metronome synchronization. This study examines both structure of autocorrelation functions (ACFs) and the shape of probability distribution functions (PDFs) in noisy metronomes as possible sources of information involved in the synchronization process. Pacing signals varied in terms of both ACF decay and PDF shape. Statistical results support the idea that both the ACF and PDF exert independent effects on the temporal structure of gait.

METHODS

Participants. Ten healthy subjects from the University of Nebraska at Omaha volunteered to participate.

Apparatus and Procedure. In this experiment, individual Noraxon FSR SmartLead footswitches (Noraxon USA Inc, Scottsdale, Az) were connected to the heel of each foot of each subject. Then the subject covered the foot switches with their socks and shoes. The footswitches were used to collect stride time intervals. The subject was then instructed to walk around on a track surface for 12 minutes. This baseline trial was self-paced and stride time intervals were collected. The self-paced trial was used to find the average and standard deviation for each subject's preferred walking speed and variability. Computations were performed using custom MATLAB code (MathWorks, Natick, MA).

After performing the baseline condition, subjects walked in four pacing conditions. Trial order was randomized. The trials were Pink-Gaussian, Pink-Uniform, White-Gaussian, and White-Noise. Here, Pink and White refer to long-range and zero autocorrelation, respectively. Gaussian and Uniform refer to standard probability distributions. The noises were delivered as a visual stimulus. A small video screen was attached to a pair of glasses to allow the subject to see the screen with their right eye, and the environment with their left eye. The stimulus screen consisted of two fixed horizontal bars, one on the top and one on the bottom of the display. A third moving horizontal bar was placed between the two bars and moved up and down. When the bar reached the top, the subject was instructed to strike with their right heel while walking. The moving bar timing was based on the mean and standard deviation of the subject's preferred walking speed, and the statistical properties implied by each experimental condition (e.g., Pink-Gaussian). All trials lasted for 12 minutes.

Analysis Strategy. Stride time series were analyzed using Detrended Fluctuation Analysis in order to compute the Hurst exponent, a measure of statistical persistence. Experimental data were analyzed with 2_W(ACF: Pink, White) × 2_W(PDF: Gaussian, Uniform) ANOVA.

RESULTS AND DISCUSSION

That statistical analysis revealed a main effect of ACF, $F(1,9)=93.16$, $p<0.001$, as well as a main effect of PDF, $F(1,9)=6.35$, $p<0.05$. The two-way interaction was not significant. These results show that the Hurst exponents were larger in the Pink condition than in the White condition. Similarly, Gaussian distributions produced larger Hurst exponents than did Uniform conditions.

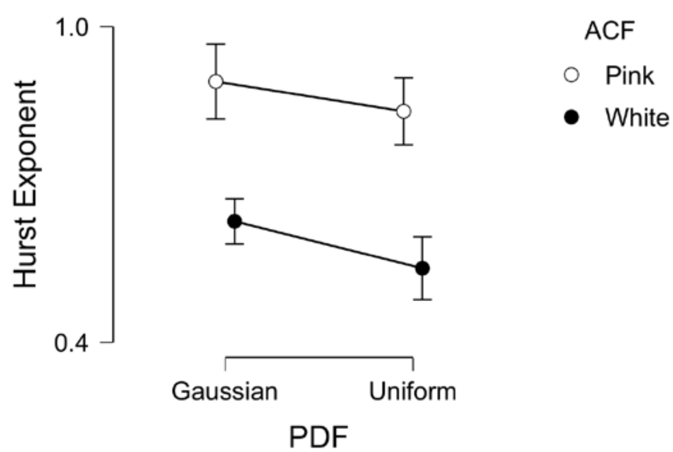

Figure 1: Hurst exponent as a function of autocorrelation and probability distribution functions.

CONCLUSIONS

In this study, we investigated the relative influence of autocorrelation and probability distribution functions on gait variability. These results suggest that both ACFs and PDFs provide relevant information that influences the time-varying structure of stride time intervals. Importantly, these properties appear to exert their influence in a relatively independent manner. Future research will investigate a broader range of ACFs and PDFs and their relevance to pathological gait.

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FOOT THERMAL RESPONSE TO SHEAR FORCE MAGNITUDE DURING TURNING GAIT

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Presentation Preference: [**Podium**]

INTRODUCTION

While thermoregulation is a vital function of the nervous system in response to cold or heat stress, previous studies have demonstrated that foot temperature can significantly increase from pre- to post-activity [1, 2]. Though these temperature fluctuations may not be a problem for healthy individuals, negative consequences may arise for individuals that are unable to properly thermoregulate, such as diabetics [3].

Shear forces have been proposed as potentially having a direct influence in Δ foot temperature (i.e., change in temperature pre- to post activity). Technical challenges associated in measuring shear have hampered further research [4]. Recent studies utilizing custom shear force plates have revealed the influence of shear on Δ foot temperature within the forefoot segment [5]. Another method of potentially exploring this relationship is through curved path walking which has been shown to have higher magnitudes of shear compared to straight line walking [6]. Toe-walking on a standard force plate in particular, may be a simpler method of exploring this relationship while mitigating the influence of shear forces from adjacent segments onto the forefoot segment.

The purpose of this study is to investigate the thermal response of the foot to varying magnitudes of shear forces during barefoot curved-path toe-walking. We hypothesized that foot temperature increase will be related to a greater shear force (i.e. a higher magnitude of shear will occur for a smaller radius). We also hypothesized that the external foot will experience greater shear and thus have a higher temperature increase compared to the internal foot.

METHODS

14 retroreflective markers were placed on the feet to quantify motion. Pre-walking temperature measurements were taken by a thermal imaging camera (Figure 1A), prior to the first walking condition and between each condition. Subjects walked barefoot on their toes for 5 minutes at a speed of 1.0 m/s for three radii (1.0, 1.5, and 2.0 m). Speed was controlled using a light timing system. After post-trail assessments (Figure 1C), the subject's feet were cooled with 70% isopropyl alcohol and the subject was rested for 20 minutes. The entire foot region was defined manually by tracing the outline of each foot, performed by one researcher using the thermal camera software. The forefoot region was defined by manually tracing and encapsulating: the toes, the first and fifth metatarsal heads.

A linear mixed effects (LME) model analysis was used to determine the relationship between the shear encountered at the foot and the thermal response of the foot (α=0.05). To determine differences between limbs a 2-way ANOVA was performed utilizing limbs and the radii condition as factors. In order to account for ground contact time, shear impulse was extrapolated to the entirety of the 5-minute trial. The LME was thus performed on temperature as a function of the accumulated shear impulse.

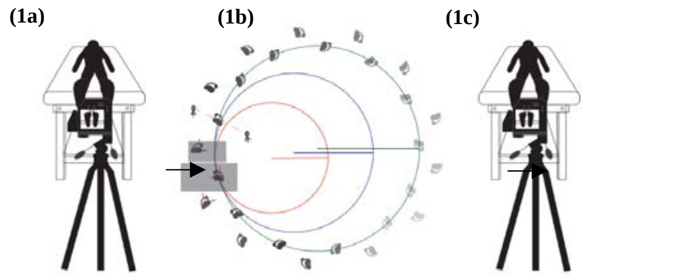

Figure 1: (1A) Pre-trial baseline temperature measurement. (1B) Subjects walked for 5 minutes on their toes in each of the three marked radii of curvature on the floor (1.0, 1.5 and 2.0 m). (1C) Post-trial temperature measurement.

RESULTS AND DISCUSSION

The external limb had a greater resultant shear impulse compared to the internal limb ($p < 0.0001$). Duty factor was greater on the external limb compared to the internal limb ($p < 0.0001$). Medio-lateral impulse was greater on the external limb compared to the internal limb ($p < 0.0001$). No significant main effect of limb side was observed in Δ entire foot temperature (p= 0.18) nor in the forefoot (p= 0.26).

Shear impulse was positively associated with entire foot temperature (p = 0.0003), and forefoot temperature (p = 0.0008), in which every unit of increase in shear (normalized to body weight) increased the entire foot and forefoot temperature by 0.08 °C ± 0.02 S.E. and by 0.14 °C ± 0.039 S.E., respectively.

CONCLUSIONS

Our first hypothesis was supported where Δ foot temperature increased as shear magnitude increased. This is further supported through the regression analysis of the forefoot region, where the shear forces were presumably acting, yielding a higher estimated slope in temperature compared to the entire foot temperature. Our secondary hypothesis was partially supported as shear magnitude was higher in the external limb compared to the internal limb though temperature was not significantly different between limbs.

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PEAK FREQUENCY OF NEURAL ACTIVITY IS SIMILAR DURING MOTOR SYNCHRONIZATION WITH PERIODIC AND VARIABLE METRONOMES

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Presentation Preference: **Podium**

INTRODUCTION

Motor synchronization with periodic rhythms is associated with a peak in brain activity at the frequency of the metronome. However, neural activity exhibits non-periodic rhythms known as fractal fluctuations [1], and it is unknown how neural activity synchronizes with non-periodic rhythms. We hypothesize that neural activity will synchronize with the fractal rhythm and show lower amplitude activity at the mean frequency because fractal rhythms display a wider distribution of beat intervals around the mean frequency.

METHODS

Twenty healthy young adults (24.6 ± 2.72y.o.) sat in a dimly lighted room and were instructed to look at their finger while tapping on a small pressure sensitive pad while wearing an electroencephalogram (EEG). They listened to metronomes (periodic, fractal, and random) through a loudspeaker while performing synchronized finger tapping tasks. After artifact removal and pre-processing steps, we identified the frequency of the peak amplitude around the metronome mean frequency (2 ± 0.5 Hz) in electrodes Fz (Midline Frontal) and Oz (Midline Occipital). Fz and Oz are known to exhibit peaks of activity in response to auditory [2] and visual [3] stimulation, respectively. Brain activity was z-score normalized to reduce individual and trial differences in mean cortical activity. One-way ANOVAs were used to compare the conditions for each electrode. Significance threshold was set at $p<0.05$.

RESULTS AND DISCUSSION

For all metronomes, the peak amplitude was on average located around 2Hz (Figure 1). While there were no significant differences between conditions ($p=0.341$ and $p=0.212$ for Fz and Oz, respectively), it is important to notice that there were large inter-individual variations. However, for some participants there was no visually clear peak around 2 Hz, in particular for the non-periodic metronomes. This lack of ability to compare the distribution of amplitudes at the frequencies of the metronome may be due to noise in the cortical recordings, or other cortical processes being performed. This may also suggest that different mechanisms underlie motor synchronization in these participants. Future analyses will include non-parametric assessment to determine the goodness of fit between the metronome and cortical recordings. This work will help us to better understand how human brains perceive and support motor synchronization with biologically relevant rhythms.

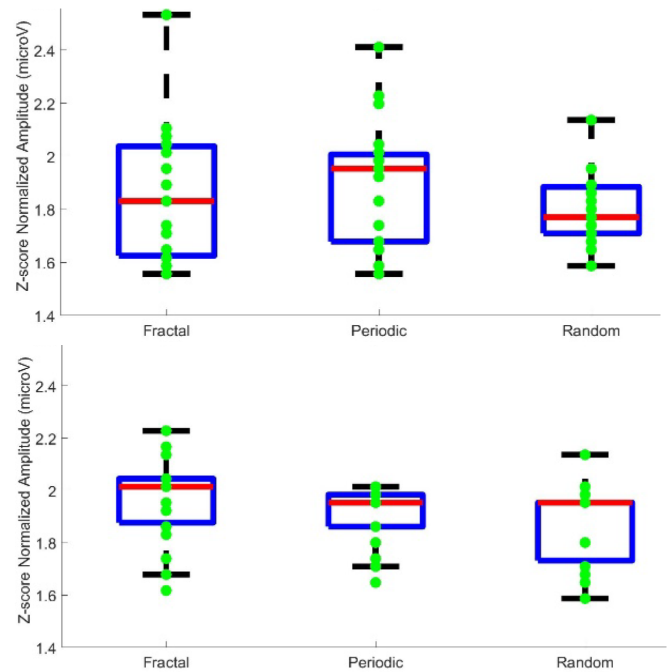

Figure 1. Peak frequencies of the Fz (top) and Oz (bottom) electrodes during synchronization with different forms of metronomes. Classical boxplots were used to indicate median, quartiles, and extent of the data (whiskers). Individual values are represented by green circles. Peak frequencies between 1.5 and 2.5 Hz do not demonstrate differences between metronomes but display large individual difference in both the Fz and Oz electrodes. Participants who displayed the highest peak frequency in one condition did not display the highest peak frequency in other conditions.

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Quantifying the effect of visual feedback on the orthogonality of balance control during gait

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Presentation Preference: [**Poster**]

INTRODUCTION

Previous gait research has shown that the ratio of anteroposterior (AP) and mediolateral (ML) step width variability reversed when the direction of progression changed from forward to sideways walking [1]. Additional research has shown visual perturbations induce substantial lateral variability but only considered the effects of sudden perturbations during otherwise normal walking [2]. However, it is not clear from these studies if the orthogonal shift in variability was an effect of change in the orientation or an effect of visual feedback from a natural environment with optic flow. In addition, it is also not clear if the orthogonal shift in variability was gradual or discreet as the difference between the direction of progression and that of optic flow increases. Our goal is to advance current literature by quantifying the orthogonal relationship between gait and balance control as well as determine the contribution of vision and proprioception to this relationship. Quantifying the relationship of balance and gait control over a range of sensory feedback signals may provide novel insights, which can be used to improve current neurorehabilitation training paradigms.

METHODS

19 participants (6 female, 13 male; 22 to 31 years) performed six 5-minute treadmill walking trials at a self-selected preferred walking speed (PWS). The first trial was used to familiarize the subject with the setup. All trials were performed in an immersive virtual reality (VR) environment where a virtual path was displayed on a screen in front of the treadmill. After the first five-minute baseline trial in which the VR and the support surface were not oscillating, the following 4 trials comprised of a random order with either VR environment or treadmill oscillations or both (congruent or incongruent) were completed. In the oscillatory conditions, the treadmill and/or VR environment oscillated in the transverse plane. When both treadmill and VR are oscillating, participants walk at a PWS while the platform and the virtual path both oscillate between 0.2 Hz and 0.4 Hz in the same or opposing directions.

Marker position data series synchronized with VR oscillatory time series will be recorded and processed using lab-designed Matlab (Mathworks, Natick, MA) code. The centroid of 5 reflective markers (ASIS, PSIS, sacrum) around the pelvis will be used to quantify the three-dimensional movement of the CoM. Spectral analysis will be performed on unfiltered sacral marker data to determine the effect of the conditions on power spectral density. Foot placement, step length, CoM position, and sway area variability will be calculated and repeated measures ANOVA will be performed for each dependent variable with conditions as the repeating factor.

RESULTS AND DISCUSSION

The continuous steady state characteristics of normal walking, walking on a moving platform, and walking in an environment with conflicting sensory information has been collected from 19 healthy young adults. Initial results indicate that balance control is sensitive to conflicting visual information.
Our results also support recent findings that show non-dominant-leg foot placement is more variable than dominant-leg foot placment [3].

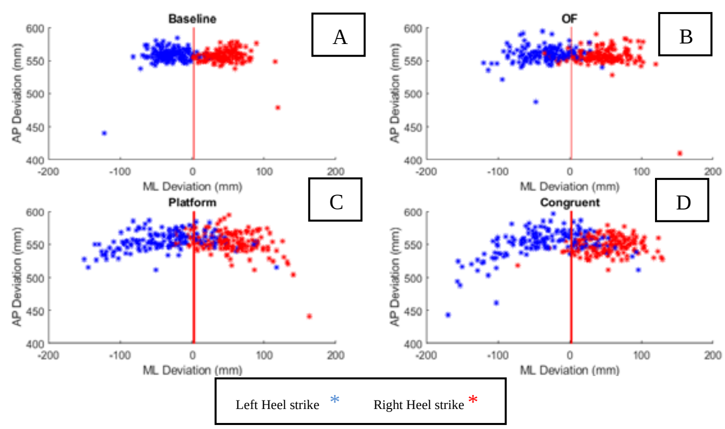

Figure 1: The distribution of foot placement locations for (a) baseline walking, (b) oscillating optic flow, (c) oscillating support surface, and (d) congruent (matched) support surface/optic flow oscillations (Figure 1). Compared to (a), all other conditions display an increased foot placement variability.

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FUNCTIONAL AND COORDINATION OUTCOMES OF AN 8-WEEK INTERVENTION USING A 3D PRINTED PROTHESIS: A CASE STUDY

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Presentation Preference: [**Poster**]

INTRODUCTION

By the year 2050, it is expected that 3.6 million people will have upper limb amputations[1]. Despite the increase in functionality provided by prostheses, a recent study found that 45% of children with upper limb deficiencies reject their prosthetic device[2]. There is a critical need to determine quantitative parameters to assess prosthesis usage and movement variability to provide the fundamental information required to objectively quantify prosthesis usage and associated benefits. Additionally, the literature which describes training paradigms and behavioral interventions for children with congenital upper limb deficiencies is sparse.

Training paradigms for acquired amputees and stroke survivors focus on interlimb transfer paradigms to transfer motor repertoires from the non-affected limb to the affected limb[3,4]. This dynamic approach provides useful tools for the assessment of limb coordination and associated variability[5] especially when examining inter-limb coordination and gross manual dexterity[6].

Thus, the purpose of this study is to assess temporal synchrony of hand movement and gross manual dexterity after completing an 8-week home intervention. We hypothesized that bimanual coordination will be more synchronous and there will be an increase in unilateral gross manual dexterity after the completion of an 8-week home intervention.

METHODS

The investigation was approved by the UNMC Institutional Review Board. The research subject evaluated in this study was a 4-year old female (height; 106 cm weight; 15.88 kg) with a transradial congenital upper limb deficiency. The 3D printed prosthesis was designed and scaled to be as proportional and symmetric to the length and circumference of the participant's non-affected arm. The scaling of the 3D printed prosthesis was performed remotely through the use of photogrammetric methods of anthropometric measurements. One week after baseline measures were recorded the subject will complete an 8-week intervention program. An occupational therapy student and graduate assistants from the University Of Nebraska Omaha Department Of Biomechanics will perform 3 home visits per week and administer a training protocol that consists of utensil, paper, timer, dressing, and balance activities.

Box and Block and bimanual coordination assessments were performed at baseline and 3 months after the start of the study. Unilateral gross dexterity upper-limb prosthetic performance was assessed using a Box-and-Blocks test. This test utilizes a partitioned box filled with identical blocks. The number of blocks transferred between partitioned areas of the box was used as a measure of motor function.

The subject will perform a novel reaching task uni-manually (3 trials for each hand) and bimanually (3 trials using both hands). The task will require the participant to start from a standard position and then reach forward and grasp (hand-to-tray), transport and place tray on a ledge (tray transport), and then return the hands to the starting position (hand return). Temporal synchrony and inter-limb coordination will be adapted from the procedures previously described by Kilbreath et al. Preliminary baseline calculations of temporal synchrony are illustrated in Figure 1.

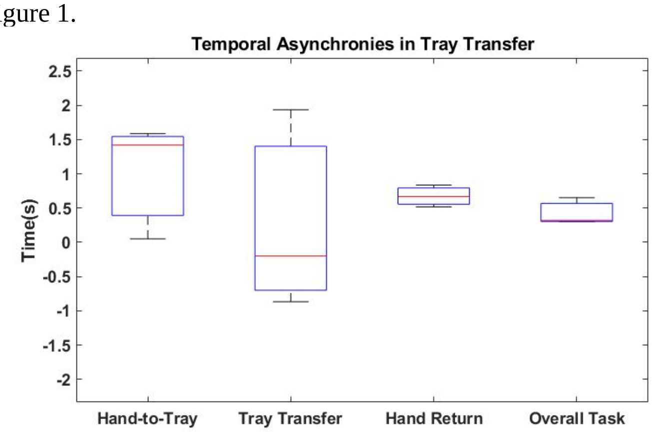

Figure 1: Box and whisker plot indicating the temporal asynchrony in tray transfer for baseline assessment. Positive values demonstrate non-affected limb leading.

ANTICIPATED RESULTS

Based on previously reported data and preliminary results, the anticipated results of this study include a increase in temporal synchrony while completing bimanual coordination test and an increase in blocks transferred in the box and block test. The 8-week intervention program will ensure repetition of reaching movements is completed by the research participant while using 3D printed prosthesis and non-affected arm. Increasing prosthetic home usage will create better outcomes in bimanual and gross manual dexterity motor assessments.

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EFFECTS OF NOVEL TOOL USE: CORTICAL AND FUNCTIONAL MEASURES IN CHILDREN USING A PROSTHETIC SIMULATOR

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Presentation Preference: [(2) **Poster]**

INTRODUCTION

The Centers for Disease Control and Prevention estimates that 1,500 babies are born every year with upper limb reductions [1]. Additionally, there were a total of 1.6 million people living with loss of a limb in 2005, which is projected to double to 3.5 million by the year 2050 [2]. While prostheses aim to enhance the function of these individuals, it is estimated 45% of children with body-powered prostheses reject their prosthetic [3].

There is little literature which investigates the motor control mechanisms that may explain this high rejection rate in children. This lack of information is due, in part, to the low availability of children with upper limb reductions to participate in research studies. One proposed solution to this problem is the employment of prosthetic simulators. These devices serve as functional homologues to the prostheses prescribed to children with upper limb deficiencies but can also be fitted to any typically developing child or adult. However, these simulators have primarily been studied by testing their ability to allow for cross education from the unaffected limb to the affected limb [4].

The purpose of this investigation is to determine the efficacy of prosthetic simulators by determining if the simulators produce similar cortical and neuromuscular activation effects compared to actual prosthesis use. To this end, our dependent variables will be hemispheric dominance within the motor cortex and co-contraction of the wrist musculature. Our hypothesis is that use of the simulators in typically developing children will produce significantly higher levels of ipsilateral dominance and co-contraction, which are expected results from prosthesis users.

METHODS

The investigation was approved by the UNMC Institutional Review Board. For children under six years of age, the study will be explained to both the parents and children, before parents sign a parental permission. For children aged six years or older, an assent will be detailed by the principle investigator, which will be signed by both parties.

Children with partial-hand upper limb deficiencies (ULD, n = 5) with body powered prosthetic devices and healthy typically developing age and sex matched children (TD, n = 10) will perform the box and blocks test, with an fNIRS device (NIRx NirSport2) recording activity from the primary motor cortex. Activation levels will be used to measure hemispheric dominance. The box and blocks test is a gross manual dexterity test that requires the participant to move blocks from one side of a partitioned box to the other, and will be performed for three trials per limb. ULD children will utilize both their unaffected limb and their affected limb using their prosthesis. TD children will utilize both limbs, as well as their left limb using a simulator (Figure 1).

Participants will perform maximum voluntary contractions (MVCs) using the wrist flexors and extensors, with EMG electrodes (Delsys Trigno Avanti) placed over the flexor carpi ulnaris and the extensor digitorum muscles. MVCs will be performed before and after testing with the box and blocks. Co-contraction will be measured as the level of antagonistic activation over agonistic activation.

Figure 1: A 3D Printed Partial Hand Prosthetic Simulator

ANTICIPATED RESULTS

Based on preliminary data and previous reporting in the literature, the anticipated results of the study include significantly higher levels of co-contraction between the affected limbs of ULD participants and the sound limbs of TD participants. TD participants may exhibit significantly higher levels of extension co-contraction in their left limb during their posttest MVC compared to the pretest MVC. ULD participants will exhibit significantly more ipsilateral dominance than TD participants during the box and blocks test. TD participants using the simulator will have more ipsilateral dominance during the box and blocks task compared to TD participants not using a simulator.

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OPTIC FLOW WHILE WALKING AND TALKING DOES NOT ALTER SPEECH FLUENCY BUT MAY ENHANCE WLAKING STABILIYT

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INTRODUCTION

Aging is related to a decrease in locomotor performance with changing sensorimotor and muscular systems[1], and is associated with declining cognitive functions. Even more so, gait alterations observed when a secondary task is involved such as walking while talking, has been suggested as a meaningful predictor of fall risk status. Walking while talking is considered a high cognitive load situation (HCLS) due to the allocation of attentional demand.[2] However, much prior research has been done on a treadmill, limiting visual sensory information important to locomotor control. Previously we have shown that by adding optic flow (OF) during HCLS (i.e. letter fluency), older adults enhanced gait parameters compared to walking without optic flow.[3] It is important to determine if these findings extend to a real-world HCLS, walking while talking on a cellular phone. Thus, the purpose of this study was to investigate the hypothesis that the presence of OF would improve gait compared to completing the HCLS when walking without OF (no optic flow; NOF).

METHODS

Fifteen healthy, older adult subjects (71±5 yrs; 8 males), able to walk 60 meters without an assistive device, were recruited from senior wellness centers within the community. Subjects completed: 1) talking only while seated; 2) walking only (single task, ST-NOF); 3) walking with optic flow (ST-OF); 4) talking while walking without optic flow (HCLS-NOF), and 5) talking while waking with optic flow (HCLS-OF). Walking was done on a self-paced treadmill and talking was done on a cell phone, with each trial lasting 9 min. Three conversation topics were randomly selected from a predetermined list. Walking performance was quantified using mean step width and speed. Step width and gait speed were selected because these are considered fall risk indicators. Word count was measured to evaluate speech fluency as cognitive performance. 2x2 repeated measures ANOVAs were conducted to compare gait performance within two optic flow conditions (OF and NOF) and two HCLS levels (walking only; ST, vs. talking while walking; HCLS). To compare means for word count, one-way repeated measures ANOVAs were conducted to compare means across the three talking conditions (talking only, HCLS-NOF, and HCLS-OF). Statistical significance level was α=0.05.

RESULTS AND DISCUSSION

For walking performance, there was a main effect of OF for step width. HCLS-OF had significantly narrower step width compared to HCLS-NOF (p=.048; Table 1). There was no main effect of HCLS nor was there an interaction. These gait results partially support our hypothesis demonstrating an improvement in gait performance (step width narrowed) during OF. This may indicate that visual flow information influences mediolateral stability while walking. For gait speed, there was main effect of HCLS (p=.009), but no main effect of OF nor interaction. Gait speed was slower under HCLS, demonstrating decreased gait performance when performing a secondary task. This result could be related to the use of self-paced treadmill walking,[4] allowing them to adjust their speed constantly to adapt to task demands. For word count, there was no main effect of HCLS (Table 1). It is possible that gait speed was slowed under HCLS tasks to maintain cognitive performance as demonstrated when talking only.

CONCLUSIONS

Optic flow (OF) resulted in narrower step width, which is a typical finding in someone with stable gait. This may be due to the necessary sensory information provided by OF when walking, and especially important for walking on a treadmill when flow is typically not present. In contrast, older adults appeared to sacrifice walking performance by walking slower, to maintain cognitive performance. The results of this study may be confounded by the use of a cell phone as using a cellular phone to talk may lead to unintentional blind spots in the visual field. It may also be considered a motor task to hold the phone steady while walking. It is important to understand the interplay between sensory and muscular systems in the aging process to assist older adults in maintaining or enhancing gait and cognitive performance. Individuals have varying levels of physical and cognitive reserve capacities to successfully complete tasks alone or in combination. It would be valuable to include personal factors to determine these capacities. Additionally, research on speech and speech fluency remain exploratory and warrant more investigation.

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ACKNOWLEDGEMENTS

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Table 1: Mean (standard deviation) of single and dual task performance

	Step Width (mm)*		Gait Speed (m/s)^		Word Count (n)
	ST	HCLS	ST	HCLS	
Talking only					1140 ± 388
NOF	167.15 ± 53.59	167.48 ± 44.30	1.20 ± .19	1.18 ± .16	1050 ± 391
OF	150.42 ± 50.37	157.82 ± 46.10	1.31 ± .18	1.20 ± .18	1072 ± 276

Note: ST = single task; HCLS = high cognitive load situation; NOF = no optic flow; OF = optic flow; * indicates main effect of OF; ^ indicates main effect of HCLS

THE EFFECT OF BLOOD FLOW OCCLUSION ON FOOT TEMPERATURE DURING AND AFTER WALKING

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Presentation Preference: **Poster**

INTRODUCTION

Patients diagnosed with diabetes and peripheral artery disease (PAD) suffer from decreased blood flow to their lower limbs. The effects of such complications include the inability to regulate body temperature and the formation of ulcers on the plantar surface of the foot [1]. Understanding how humans regulate foot temperature during or after locomotor activities could be a key component to diagnosing and treating this symptom of diabetes and PAD. Unfortunately, the mechanisms that explain foot temperature response are currently unclear. Previous works have found that there is a strong positive correlation between plantar surface temperature and blood flow during rest in healthy populations [2-3]. However, there is no work highlighting the role of blood flow in temperature change during and after walking in healthy subjects. The purpose of this study is to investigate the effect of different levels of blood flow occlusion in one of the lower limbs in healthy subjects. We hypothesize that: (1) the temperature of the plantar surface of the foot will decrease after walking with greater levels of blood flow occlusion and (2) greater levels of blood flow occlusion will cause the temperature of the occluded foot to return to equilibrium at a faster rate after releasing pressure from the occluded limb.

METHODS

We plan to recruit 25 healthy subjects. Lab shoes and socks will be standardized and provided for all subjects. There will be three walking conditions in randomized order: no occluded blood flow, half occluded blood flow, and fully occluded blood flow. Before walking, the subject's arterial occlusion pressure (AOP) will be determined by their systolic blood pressure (SBP) and tissue padding coefficient (K_{TP}) [4]. The subject will rest in a supine position for 20 minutes to allow the body to equilibrate with the room. After 20 minutes have elapsed, a pre-walking thermal image will be taken (FLIR Systems, USA). An inflatable tourniquet (KAATSU Global, Japan) will be strapped to the subject's right thigh and inflated to the subject's AOP upon arrival to the starting point on the track. The subject will walk overground for 10 minutes at a speed of 1.25 m/s. The speed will be kept by a pacer walking with the subject. The subject will rest after walking with the tourniquet still strapped to the thigh, if it was used in that condition. A post-walking thermal image will be taken every 30 seconds for 5 minutes, thereafter the tourniquet will be deflated. A time-lapse will continue for another 5 minutes after deflation with images being captured every 30 seconds. The subject will rest for 20 minutes after the time-lapse is complete to allow the body to reach equilibrium with the room before the next walking condition commences.

Thermal images taken will be analyzed using a custom written MATLAB script (Figure 1). Regions of interest (i.e. hallux, metatarsophalangeal (MTP), medial arch, lateral arch, and heel) will be identified and analyzed. Image-based parameters are extracted from these regions, such as mean and standard deviation. Temperatures of both feet across all three conditions will be compared using a two-factor repeated measures ANOVA where the two factors are occlusion level (zero, ½ AOP, full AOP) and limb (occluded or not occluded).

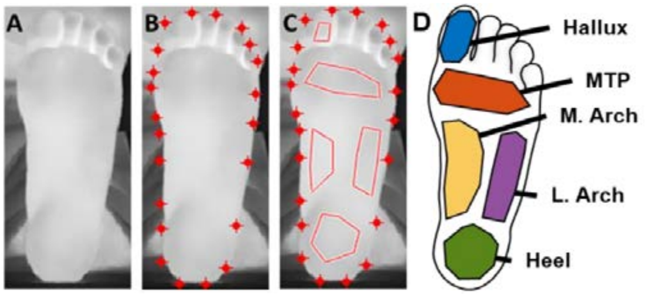

Figure 1: A) An individual foot is identified. **B)** The foot is outlined by the user. **C)** Regions of interest are highlighted and temperature measurements are recorded. **D)** Hallux, MTP, medial arch, lateral arch, and heel are highlighted as regions of interest [5].

RESULTS AND DISCUSSION (in progress)

We expect temperatures of the occluded foot to be significantly lower than temperatures of the unoccluded foot after walking. We also expect to see temperature return to equilibrium at a faster rate after deflation of the tourniquet at higher levels of occlusion.

CONCLUSION

Our findings may help us understand the role of blood flow in temperature regulation, as well as gain new insights for diagnosis and treatment of pathologies reducing blood flow.

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ACKNOWLEDGEMENTS

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QUADRICEPS PERFORMANCE IS ASSOCIATED WITH KNEE MECHANICS DURING SQUATTING 6 MONTHS POST-ANTERIOR CRUCIATE LIGAMENT RECONSTRUCTION: A PRELIMINARY ANALYSIS

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Presentation Preference: [**Podium**]

INTRODUCTION

Quadriceps strength and movement deficits are common after anterior cruciate ligament reconstruction (ACLR) and persist up to four years post-operatively [1,2,3]. Rate of torque development (RTD) has been associated with irregular loading during gait that contributes to knee osteoarthritis [1]. Further, quadriceps strength asymmetry at time of return-to-sport has been shown to increase the risk of secondary knee injury [4].

Squats are commonly performed in rehabilitation protocols after ACLR and are an essential functional movement. A weak correlation between quadriceps strength and knee flexion angle during squats has been demonstrated [5], but the relationship between quadriceps strength and squat kinetic variables is currently unknown.

The purpose of this analysis was to assess the association between quadriceps performance and knee joint mechanics during bilateral and unilateral squats at 6 months post-ACLR.

METHODS

This preliminary analysis included participants within an ongoing, observational cohort study who completed testing 6 months after ACLR (n=11; 7 females, 4 males; age: 20±4.2 years). Exclusion criteria included concomitant injury to other knee ligaments requiring surgical treatment, baseline cartilage damage, planned meniscectomy, or previous injury or surgery in either knee.

Quadriceps muscle performance was tested using an electromechanical dynamometer. Participants completed 3 trials of maximal voluntary isometric contractions (MVIC) into knee extension with the knee positioned in 90° of flexion. In the same session, participants performed 3 sets of 5 bilateral and unilateral squats at self-selected speed using a reliable retroreflective marker set placed on the trunk and lower extremities. Participants were instructed to squat as low as possible without increased pain or instability. Kinematic data was collected at 120 Hz using an 8-camera motion capture system and kinetic data was collected at 1080 Hz using two embedded force plates.

Analysis of quadriceps performance included peak torque limb symmetry index (LSI) (involved/uninvolved x 100%) and RTD LSI during the first 200 ms of the MVIC. Biomechanical variables of interest in the involved limb included peak external knee flexion moment, the impulse of the external hip flexion moment to knee flexion moment ratio (hip/knee ratio), and peak knee power.

Separate linear regression models were used to determine the association between quadriceps performance and each squat variable of interest. Graft type (patellar/quad tendon autograft (BTB/QT) vs. hamstring autograft (HT)) and concomitant meniscus repair were entered into each regression model first followed by quadriceps peak torque or RTD LSI.

RESULTS AND DISCUSSION

After controlling for graft type (BTB/QT (n=9); HT (n=2)) and meniscus repair (n=5) ($R^2 = 0.184$), RTD LSI (64.2±26.8%) explained an additional 60.1% of the variance (R^2=0.785, p=0.010) in peak external knee flexion moment. However, only RTD LSI was a significant predictor (β=0.797, p=0.003). A similar trend was present between peak torque LSI (65.2±21.7%) and peak knee flexion moment but was not significant in this sample. After controlling for graft type and meniscus repair (R^2=0.361), peak torque LSI explained an additional 51.4% of the variance in peak knee power (R^2=0.875, p=0.002) and was the only significant predictor in the model (β=0.753, p=0.001). Similarly, RTD LSI explained an additional 55.0% of the variance in peak knee power during the unilateral squat task (R^2=0.910, p <0.001) in the involved limb. Graft type (β=0.384, p=0.024) and RTD (β=0.763, p<0.001) were significant predictors in this model. Hip/knee ratio during the unilateral squat was not associated with quadriceps performance. No significant relationships existed between quadriceps performance and bilateral squat biomechanical variables.

CONCLUSIONS

The results of this preliminary analysis suggest that quadriceps performance is associated with measures of knee joint loading during unilateral squats after ACLR. Rehabilitation protocols may need to include training for quadriceps power production in addition to rebuilding strength in the operative limb to restore normal movement patterns.

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SUBJECT SPECIFIC STRENGTH AND KNEE ALIGNMENT ANGLES TO IMPROVE KNEE JOINT CONTACT FORCE PREDICTIONS IN INDIVIDUALS POST TOTAL KNEE ARTHROPLASTY

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Presentation Preference: Poster

INTRODUCTION

Within 10 years of a primary total knee arthroplasty (TKA), approximately 50% of patients require an additional TKA on the contralateral limb [1]. This may be the result of asymmetric gait patterns that offload the surgical limb and put additional stress on the contralateral limb [2]. It has been shown that excessive loading of the contralateral limb increases the risk of osteoarthritis (OA) progression in that limb [3]. However, little is known about how knee joint contact forces (JCF) are distributed between legs during asymmetric gait or their effect on the risk of contralateral knee OA progression. Furthermore, no simulation studies have adjusted a model to make it subject specific for both the frontal plane tibiofemoral angle (ϴ) and lower limb strength, two factors very important in estimating accurate knee JCF [4], [5]. Therefore, the purpose of the current study was to investigate both medial and lateral condyle knee JCF in both the surgical and non-surgical limbs of individuals post unilateral TKA using a subject specific model for both lower leg strength and ϴ.

METHODS

One individual (height: 1.75 m, mass: 102.1 kg) 6 months post unilateral TKA performed overground walking trials at a self-selected speed across two in ground force platforms. Musculoskeletal modeling was performed using OpenSim simulation software [6] to calculate medial and lateral knee JCF utilizing a model created by Lerner et al. [4]. Marker location data from a standing calibration trial and the subject's body mass were used to scale the model. The subject's knee flexor and extensor strength were obtained through a maximal voluntary isometric contraction of both knee flexion and knee extension. The subject was seated with hips and knees flexed to 85° and 60°, respectively [7]. Flexor and extensor muscle strength were scaled from OpenSim's generic strengths, and new subject specific values were entered into the model for each flexor and extensor muscle. The subject's frontal plane ϴ was measured as the angle between a line connecting the center of the femoral canal to the center of the femoral condyles and a line connecting the center of the tibial plateau to the center of the tibial medullary canal. This was done using a radiographic image of the subject's knees (Figure 1) and MATLAB (Natick, MA, USA). The subject's ϴ was subtracted from 180 and divided by 2 to adjust the femoral and tibial alignment symmetrically in the model. Following scaling, OpenSim's inverse kinematics, residual reduction analysis, static optimization, and joint reaction analyses were performed. This procedure was performed for each model: no adjustments, subject-specific strength only, knee alignment adjustment only, subject specific strength and knee alignment adjustment.

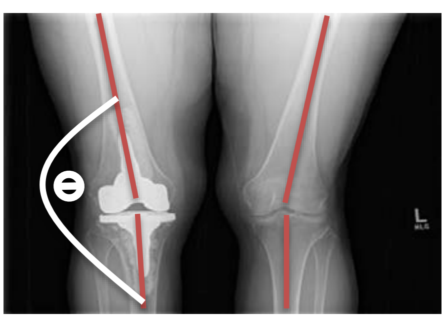

Figure 1. Measurement of the subject's tibiofemoral angle (ϴ) from a posterior radiographic image.

RESULTS AND DISCUSSION

When comparing the four models, the model with no subject-specific adjustments had the largest medial condyle knee joint contact force and the fully informed model had the lowest medial condyle knee joint contact force for both knees (Table 1). In all four models the left (surgical) knee was loaded more than the right nonsurgical knee. These data indicate when estimating knee joint loading, both subject-specific strength and knee alignment should be considered when assessing the magnitude and medial-lateral distribution of force.

CONCLUSIONS

The current study demonstrates how subject specific strength and tibiofemoral joint angles can affect a model simulation. Future studies should investigate which model is best for predicting accurate knee JCF and how these forces affect contralateral knee OA progression.

ACKNOWLEDGEMENTS

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Model	Nonsurgical Medial JCF (BW)	Nonsurgical Lateral JCF (BW)	Surgical Medial JCF (BW)	Surgical Lateral JCF (BW)
No adjustments	-3.02	-1.95	-5.10	-1.95
Strength only	-2.63	-1.86	-3.89	-1.34
Knee Alignment Only	-2.92	-2.19	-4.45	-2.73
Strength and Knee Alignment	-2.56	-2.70	-3.85	-2.04

CHARACTERIZING LEVODOPA-INDUCED DYSKINESIA IN PARKINSON'S DISEASE USING ACCELEROMETRY

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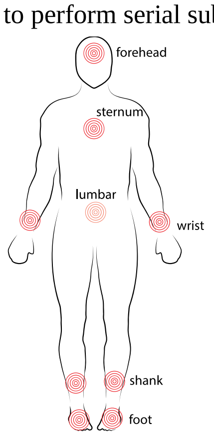
Presentation Preference: **Poster**

INTRODUCTION

Levodopa-induced dyskinesia is a major problem associated with the long-term use of levodopa for symptomatic treatment of Parkinson's disease (PD) [1]. These involuntary hyperkinetic movements can become disabling and may interfere with quality of life. Further, previous research suggests that levodopa-induced dyskinesia increases postural instability [1,2]. The aim of this study is to determine the effect of levodopa-induced dyskinesia on postural sway using accelerometry.

METHODS

We recruited a total of 26 participants with idiopathic Parkinson's disease; 14 with a spectrum of dyskinesia severity and 12 without clinical signs of dyskinesia. All participants were taking L-dopa as part of their antiparkinsonian medication regimen. Participants were tested in the morning in their practical OFF state, that is, at least 12 hours after their last intake of antiparkinsonian medications. Subsequently, they were retested in the ON state, that is, 1 hour after a L-dopa challenge dose that was approximately 1.25-fold of their regular L-dopa dose. In the single task condition, participants were asked to stand quietly for 30 seconds with their arms hanging along their sides while looking at an art poster 2 meter ahead. To provoke dyskinesia, participants will perform a cognitive task [3]. During the dual task condition, participants were asked to perform serial subtractions of 3, starting at e.g. 223.



Nine inertial sensors (Opal v1, APDM Inc., Portland, OR) attached to the forehead, sternum, lumbar spine around L3-L4, bilateral wrist, bilateral shank, and bilateral dorsum of each foot were used to record segmental movements (Figure 1). For each of the sway conditions, the root mean square (RMS) of the anteroposterior (AP) acceleration was calculated from the lumbar sensor. Videos recordings of the sway trials were used to determine clinical ratings of hyperkinetic movements for each body part.

Figure 1: Placement of inertial sensors.

RESULTS AND DISCUSSION

In both groups, postural sway slightly increased in anteroposterior direction as an effect of medication during single tasking (Figure 2). However, during dual-tasking the increase in postural sway was confined to the participants with levodopa-induced dyskinesias in the ON medication state (Figure 3).

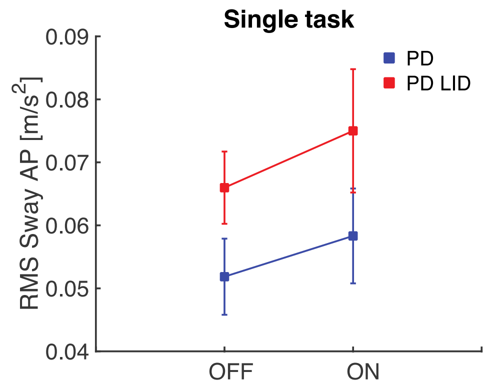


Figure 2: Effect of L-dopa on RMS Sway in anteroposterior direction during single tasking in people with PD with or without levodopa-induced dyskinesias (LID).

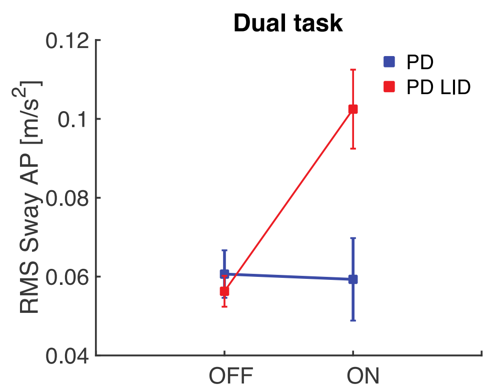


Figure 3: Effect of L-dopa on RMS Sway in anteroposterior direction during dual tasking in people with PD with or without levodopa-induced dyskinesias (LID).

CONCLUSIONS

Our results suggest that inhibitory control is compromised in dyskinetic participants, leading to an increase in postural sway while performing a cognitive task. Further analysis will be performed to characterize the contribution of involuntary movements of individual body parts to the increase in postural sway during dual-tasking.

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ACKNOWLEDGEMENTS

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EFFECT OF VITAMIN D SUPPLEMENTATION ON BALANCE IN INDIVIDUALS WITH CHRONIC KIDNEY DISEASE: A PILOT STUDY

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INTRODUCTION

Chronic kidney disease (CKD) is a progressive problem worldwide. As of 2019, 15% of adults in the US are estimated to have CKD [1]. CKD occurs when the kidneys can no longer filter blood as they should. The kidneys stop activating calcitriol creating an imbalance of calcium in the blood. Additionally, they cannot remove the phosphorus in the blood properly. Extra phosphorus pulls calcium out of the bones, causing them to weaken. Bone disease in CKD patients leads to a high prevalence of falls (>50% in CKD over age 50 years) and high risk for fracture [2]. Confounding the high risk of falls, individuals with CKD have proprioceptive sensory dysfunction, muscle weakness, and atrophy. It is important to reduce these individual's risk of falls to avoid fracture due to falling. As a measure of fall risk, balance deficits have been reported in individuals with CKD immediately after hemodialysis [3]. Well documented in literature is the effect of vitamin D in decreasing fall risk in the elderly [4]. However, a gap in our knowledge remains regarding the effect of vitamin D on balance in individuals with CKD. Therefore, the purpose of this project is to explore the effect of 3-months of vitamin D supplementation on balance in individuals with CKD.

METHODS

This project is currently in data collection. Upon completion, a total of 30 individuals with CKD will have been recruited through the University of Nebraska Medical Center and randomized into two different vitamin D supplementation groups: oral 4000 IU/day and 800 IU/day for 3 months. Currently, four subjects have been enrolled into the study (Table 1). This abstract is based upon these preliminary baseline results. Subjects performed a series of balance tests at baseline. They were then given a 3-month supply of vitamin D. After 3 months of vitamin D supplementation, subjects will return to the laboratory for post testing.

Static and dynamic balance was measured using the Neurocom Balance Manager system: the Sensory Organization Test (SOT) and the Motor Control Test (MCT). The SOT assesses the three sensory systems that encompass balance. An equilibrium score ranging from 0% to 100%, with 100% indicating perfect stability and 0% indicating a fall, was calculated for each trial. The MCT measures the body's ability to recover from unexpected external provocations. Latency is reported, the time in milliseconds for an individual's center of gravity to respond to the movement. A shorter latency is considered better. Latency scores for three trials were averaged for right and left, medium and large translations. Lastly, the subjects performed the Fullerton Advanced Balance scale (FAB) which assessed his/her ability to use somatosensory cues to maintain upright in varying situations. Scoring less than 25/40 is considered to be at risk for falling.

RESULTS AND DISCUSSION

The preliminary results are detailed in Table 1. For the SOT, normative mean scores for persons aged 20-59 years is 79.8% and for 60-69 years is 77.6%. All four subjects fell below the normative level for their age group. CKD does have a known effect on vision, and those with very severe CKD are likely to have a 6-fold increased risk of vestibular dysfunction [5]. These alterations in sensory systems are likely reflected in the lower SOT composite scores. For the MCT, normative scores for 20-59 years are 124, 117, 143, 135 ms for medium backward, large backward, medium forward, and large forward, respectively. For the MCT, normative scores for 60-69 years are 132, 124, 136, 132 ms for medium backward, large backward, medium forward, and large forward, respectively. For almost all translations of the MCT, the subjects had a longer latency as compared to the norm. Even the youngest of the subjects, aged 43, had a longer latency compared to normative values indicating balance deficits at a young age. Proprioception deficits may likely contribute to the slowed reaction to the platform translations. When comparing the FAB scores, two of the subjects demonstrate high risk of falls (<25/40); however, the youngest participant did not (39/40). It is possible that the FAB was not sensitive enough to sensory alterations associated with the disease at younger ages.

CONCLUSIONS

Based on these preliminary findings, balance deficits in individuals with CKD exist even when they have not immediately completed hemodialysis as previously reported [3]. These findings are similar to our previous findings using the NHANES study [6]. It is likely that these balance deficits exist due to alterations in sensory and muscular systems associated with the disease. As data collection continues, we anticipate reporting post scores to determine the effect of vitamin D on balance in individuals with CKD.

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Table 1: Preliminary baseline scores from enrolled subjects.

Subject	**Gender**	**Age (yrs)**	**Height (cm)**	**Mass (kg)**	**Number of years on Hemodialysis**	**FAB Score (a.u.)**	**SOT Composite Score (%)**	**Average MCT Latency (msec)**			
								Medium Backward	**Large Backward**	**Medium Forward**	**Large Forward**
S01	M	67	180	99.3	5	25	41	145	125	150	130
S02	F	54	164	134.3	11	29	71	135	130	155	140
S03	M	61	176	122	11	17	71	90	145	165	160
S04	M	43	169	90.26	3	39	72	135	130	155	140

ASSISITVE DEVICE USE AFFECTS PEAK PROPULSIVE FORCES IN INDIVIDUALS POST-STROKE

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INTRODUCTION

Stroke is the primary cause of long-term adult disability in the United States [1]. There is a correlation between hemiparetic severity and paretic (weak side) propulsive forces, thus, increasing paretic propulsion is an important goal of rehabilitation [2]. During rehabilitation, assistive devices, such as treadmill handrails or a cane, are commonly utilized. Research has demonstrated that these devices alter biomechanics; step symmetry [3] and energy cost [4] of walking change with the use of handrails, and a cane provides braking assistance [5]. However, the direct impact of assistive devices on propulsive forces and how functional ability affects this relationship is unknown. Therefore, the purpose of this study is to determine the effect of assistive device use, such as cane or handrails, on propulsive forces in individuals post-stroke with varying functional levels and experience with assistive devices. We hypothesized that the relationship between assistive device use and propulsive force will vary as a function of a subject's level of functional impairment. We further hypothesize that peak assistive device propulsive forces generated on a handrail will be greater than on a cane.

METHODS

Three participants (2M, 1F; age 67 ± 11.36 yrs; 1.77 ± 1.60 yrs since stroke) from an ongoing study with different levels of function: no history of assistive device use, past history of an assistive device use, and current dependence on an assistive device, were included in this analysis. Inclusion criteria included: age 19-80, single-chronic stroke, and ambulatory. Motion capture analysis using a full-body, 65-marker set was done both overground, using in-ground force plates and an instrumented cane, and with an instrumented treadmill and handrails. For the treadmill trials, subjects walked for three walking conditions (3 minutes each): no handrail use, light support handrail use and self-selected handrail device use. For the overground trials, subjects completed three conditions: walking with no cane, walking with a cane using light pressure and walking with a cane comfortably. Real-time feedback of the cane and handrail forces were displayed for the light-support condition on a screen in front of the participant. One subject, who was dependent on an assistive device, was only able to complete the handrail and cane conditions. The peak paretic propulsive GRF and peak assistive device propulsive force were calculated for each subject and for each trial.

RESULTS AND DISCUSSION

There is little variation in peak propulsion across treadmill conditions, however participants who were not device dependent saw a decrease in peak propulsion with cane usage (Table 1). Additionally, the peak propulsion was 116-231% greater for the overground conditions compared to the treadmill. For both assistive device conditions, 108-395% greater peak assistive device anterior force was used in the self-selected compared to the light force condition. Additionally, 87-265% more anterior force was generated on the handrails compared to the cane.

CONCLUSIONS

These preliminary results suggest that using a cane can negatively affect propulsive forces, while handrail use might not alter these forces. Though, propulsion was much lower for the treadmill conditions compared to overground, so it may not be feasible to lower propulsion with handrail use. Since an individual's functional level altered how their propulsion changed between conditions, functional level may play a role in the impact of assistive devices on propulsion.

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ACKNOWLEDGEMENTS

This research was funded by the National Institutes of Health (R15HD094194).

Table 1: Peak paretic propulsive force and peak assistive device propulsion for both treadmill & overground conditions

		Treadmill			Overground		
	Level of Function	No HR	<5% HR	SS HR	No Cane	<5% Cane	SS Cane
Peak Propulsive GRF (N)	No Assistive Device	55.30	62.01	63.87	103.42	76.35	84.88
	Assistive Device History	65.13	62.21	58.38	115.14	91.45	67.90
	Assistive Device Dependent	N/A	20.21	17.20	N/A	34.17	39.73
Peak Anterior Assistive Device Force (N)	No Assistive Device	0.00	7.94	13.09	0.00	4.56	4.95
	Assistive Device History	0.00	6.63	9.55	0.00	2.77	10.93
	Assistive Device Dependent	N/A	4.70	10.88	N/A	2.70	4.35

IMPROVEMENTS ON THE WEARABLE APARATUS FOR SLIP PERTURBATIONS

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Presentation Preference: [**Poster**]

INTRODUCTION

The Wearable Apparatus for Slip Perturbations (WASP) is a device with the ability to deliver a slip perturbation to either foot at any given point in the gait cycle. After several years of development, the device has gotten more complex. While the complexity increases, however, it is important to make sure that the device is easy to use and reliable. We believe this tool opens up new opportunities for research and potential interventions. However, adoption of the device by other labs and clinics depends on the reliability and ease of use of the device.

The WASP incorporates a slippery surface that is firmly attached to the bottom of the shoe. This slippery surface is on the upper surface of the outsole. It has a polyurethane sheet on top to provide an additional slippery surface for sliding along the interface between them. The bottom of the outsole includes nylon reinforced rubber on the bottom to facilitate a level of traction similar to an athletic shoe. A shoe wrapped in polyurethane is placed on top of the outsole and the outsole is folded up around the shoe and securely fastened to a triggering mechanism with 130lb test fluorocarbon monofilament. The monofilament forms a single loop that is shortened using a tensioning device to ensure a secure attachment to the trigger mechanism. The trigger mechanism uses a cam and follower that retracts a pin that the monofilament loop attaches too. When the pin retracts, the loop is released and the shoe slides on the top of the outsole. The cam is turned by an electric motor that controlled by an onboard Bluetooth microcontroller. The device can be triggered remotely to target a specific phase of the gait cycle.

METHODS

The WASP has gone through several iterations throughout its development. Through much pilot testing, eventually we had a design that gave us the type of perturbation that was required and worked well enough to use it to collect some data. While the device did work, there were some flaws in its functionality. For example, it was difficult to setup and resetting the device between trials took up a lot of time. There were also problems with the durability of the outsole as it would frequently tear.

Each part of the device has gone through its own iterations to improve functionality and reliability. One aspect that makes the new version of the WASP easier to reset is that the cam position automatically resets immediately after it is triggered. A new method of tensioning the monofilament loop has been made to make resetting easier and faster, (Fig. 1). The trigger mechanism also has a lower profile design that weighs less, (Table 1).

The reset times were recorded from the time the task of resetting the device began to the end of the task.

RESULTS AND DISCUSSION

The old WASP average reset time was (221 +/- 36) seconds. The new WASP reset time was (68 +/- 19) seconds.

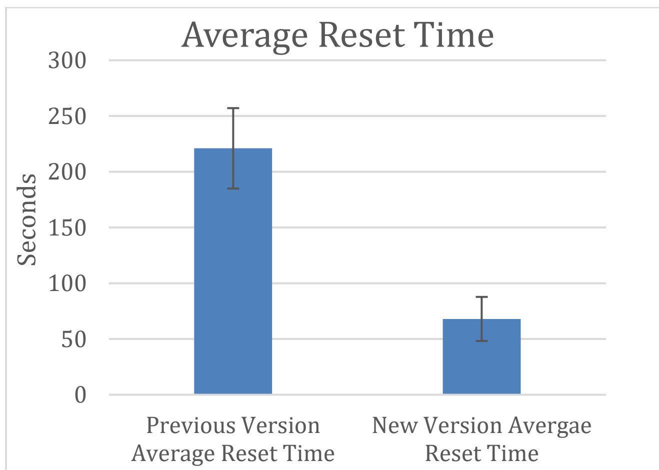

Figure 1: A comparison between the reset times of the previous and new version of the WASP

CONCLUSIONS

The WASP needs to be reliable and efficient to get good data out of slipping trial study. The WASP outsole has been updated with a more durable material to prevent tears after hard use. The trigger mechanism has been updated to automatically reset the cam. The cam profile has been updated to prolong the life of the gearbox on the motor. And an effective tensioning method has been developed to decrease the amount of time spent on resetting the WASP between trials.

Table 1: Weight Differences in Trigger Mechanism

***All units in grams**	**Old Version Weight**	**New Version Weight**	**Percent Change**
Trigger Mechanism	247	161	-34.8%

Markerless Tracking of Rapid Cockroach Running with Deep Learning

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Presentation Preference: **Poster**

INTRODUCTION

Tracking video data is a critical aspect of quantifying animal locomotion, but can be laborious and time intensive. We investigated the potential of a deep learning method, Deep Lab Cut (DLC) (Mathis & Mathis, 2019), to reduce tracking time. Specifically, we investigated the ability of DLC to track the abdomen and head of a rapid running cockroach along a rod. The American cockroach, Periplaneta americana, has the surprising ability to run both above, and inverted beneath a rod, enhancing its ability to negotiate canopy-like terrain. However, this leads to experimental difficulty to track the animal in 3D since the body is often occluded by the terrain itself. Here we tested whether the DLC method is capable of reliably quantifying 3D pose of the animal from video data that included occlusions.

METHODS

We employed DLC on an experiment in which cockroaches ran on rod at different slopes (0, ±30, ±60, ±90 deg), to simulate locomotion along stems and branches. To elicit maximal running speeds on these animals that weigh approximately 1 g, we did not place markers on the cockroaches. The rod was marked with tracking targets. Escape responses were triggered by lightly brushing the abdomen, and running responses were recorded from 3 oblique cameras at 300 Hz.

A total of 84 trials were collected. Manual tracking of each trial took approximately 1-2 hours. Instead of tracking all trials, we tracked a subset of frames, and used those to train the neural network to track the remaining frames. After tracking all frames using the neural network, we reprocessed them with DLT dv7 to fix any errors.

RESULTS AND DISCUSSION

Through the usage of DLC, the processing time does decrease significantly. Depending on the trial, digitizing the data, with the addition of DLC, took about a third of the time. As seen in figure 1a, the cockroach can run 600 ms across a 40 cm rod and that data can get digitized into a 3D trajectory as seen in figure 1b. This method has strong potential to increase the speed of experiments for animals moving over complex substrates in which their bodies are occasionally occluded by those substrates.

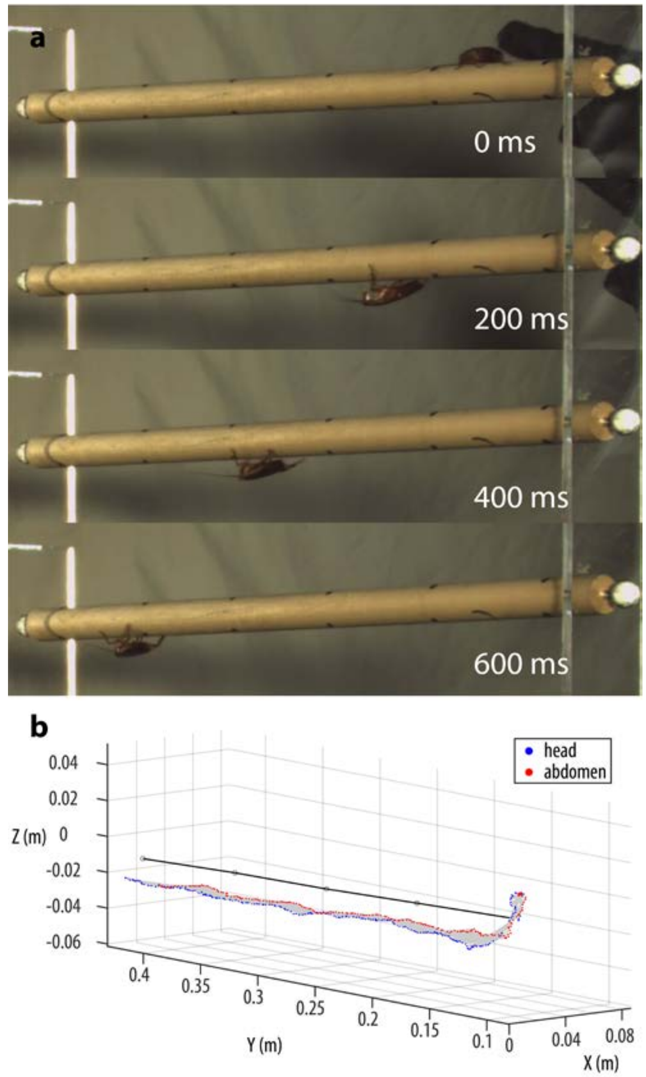

Figure 1: Representative trial of cockroach escape response. **a**. frames from high speed video data collection show cockroach body position at four times within the escape response. **b**. 3D reconstructed trajectory of cockroach body poses during the escape response. Blue and red dots illustrate the cockroach head and abdomen, and solid black line represents 3D pose of the rod's longitudinal axis.

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THE EFFECTS OF AUDITORY CUEING ON REACTIVE MOVEMENTS TO BALANCE DISTURBANCES

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Presentation Preference: Poster

INTRODUCTION

Slips and falls are a major problem, with studies showing they are the leading cause of injury in the elderly [1]. Previous research has shown that providing an auditory warning prior to a balance disturbance may improve recovery [2,3]. However, this knowledge does not address the potential of cues during walking, the context in which most slips occur, or how additional information provided by the cueing system will affect reactive movements. In order to address this knowledge gap, we have initiated a study to examine recovery measures taken to regain balance during walking where subjects will experience a variety of complex auditory cues. We hypothesize that 1) the rate of learning of an auditory cueing system for balance control is inversely related to its information content, 2) the more complex cueing systems will enable greater specificity to diverse perturbation and balance performance will increase with greater specificity of reactive stabilization responses, and 3) simpler cueing systems for balance control will enable faster reactions and optimal balance performance will be achieved by a cueing system with intermediate complexity.

METHODS

All procedures for this study will be completed in one visit to the Biomechanics Research Building at the University of Nebraska at Omaha. Participants will be outfitted with a full-body retroreflective marker set and safety harness, then placed on the Computer Assisted Rehabilitation Environment (CAREN, Motekforce Link; Amsterdam, The Netherlands), an instrumented split-belt treadmill mounted to a six degree of freedom motion base. Marker trajectories will be recorded with a 10-camera motion capture system (Vicon Motion System Ltd.; Oxford, UK). Real-time feedback of marker positions will be used to create platform perturbations given with informative auditory cues at left heel strike, totaling in 100 perturbations. Perturbation order was randomly generated through Matlab. The above protocol was piloted with two subjects, whose data is presented here.

The two pilot subjects were given the most informative level of auditory signals we plan to use. Three levels of cueing systems were developed; the first level giving a single signal indicating a perturbation, the second level giving two signals indicating a perturbation in the left or right direction, and the third level giving three signals to indicate exact perturbation direction. Auditory signals are differing tones given for 5 ms each. Participants experienced a base cue indicating that there will be a platform perturbation, a left/right cue indicating the general direction of the platform perturbation, and a final cue indicating exactly which direction the perturbation will occur: 30, 90, 150, 210, 270, or 330 degrees (Figure 1).

RESULTS AND DISCUSSION

Trunk posture analysis has been the primary focus during this initial testing period. In these subjects, absolute trunk angle range decreased over the course of trials given for nearly all perturbation types (Figure 2). This indicates a rate of learning by subjects to strengthen their trunk control in order to maintain upright balance. Given this information we will continue to move forward with the study to see if this trend is affected by cueing systems varying in complexity. Future investigation will evaluate how subjects respond to receiving different amounts of information about a balance disturbance.

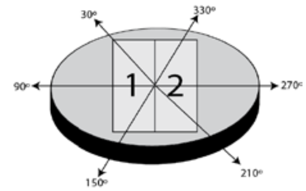

Figure 1: CAREN platform and the six perturbation directions.

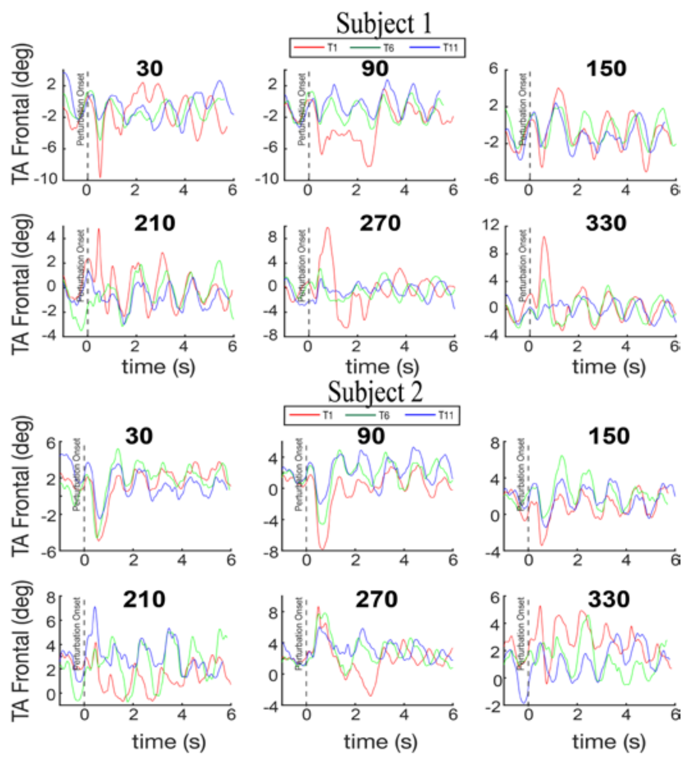

Figure 2: Comparison of absolute trunk angle in the frontal plane for the first, sixth, and eleventh trial of each platform perturbation direction.

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FORCE PRODUCTION VARIABILITY DURING LEG PRESS IN HEALTHY INDIVIDUALS

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Presentation Preference: **Poster**

INTRODUCTION

Many patients who experience knee pathologies fail to re-engage in activities they did prior to pathology, even after completing rehabilitation [1, 2]. Current rehabilitation focuses on strengthening the quadriceps using exercises like the leg press, however, it is difficult to objectively evaluate the quality of the forces produced during these exercises. Using a custom force platform, we are able to measure the forces during the leg press and evaluate their control using the Lyapunov exponent (LyE). Establishing force control norms in healthy populations provides a point of comparison for pathological populations that can be used in the future. Therefore, the purpose of this study was to evaluate force control in healthy individuals.

METHODS

Fourteen healthy individuals with no significant history of lower-extremity injury participated. Participants' one-repetition maximum (1RM) for the leg press exercise was determined using a normative data chart and their leg dominance was defined as the leg that they would kick a ball with.

All participants completed a leg press task that consisted of performing continuous repetitions of the leg press exercise for two minutes at a cadence of 60 bpm and a load of 20% of their 1RM. All force data was collected using a custom force platform at a sampling rate of 60 Hz.

LyE was calculated for the dominant limb, nondominant limb, and both limbs working together (total) using Wolf's algorithm [3]. Time lag was determined using the Average Mutual Information function and was kept individual for each participant while mode embedding dimension was used and determined using the Global False Nearest Neighbors function.

Repeated measures ANOVA with a Bonferroni post-hoc analysis was performed to compared LyE values of the dominant, nondominant, and total. Significance was determined using an alpha of 0.05.

RESULTS AND DISCUSSION

No differences were found between the dominant and nondominant limbs (p=0.516), indicating the limbs have similar force control in healthy individuals. This is in agreement with previous work that showed similar force control between limbs in healthy individuals during a simulated cutting task [4].

LyE values of the total were lower than the dominant limb (p=0.001). This difference may be because the dominant limb has a primary role in force production while the nondominant limb has a greater role in stabilizing and controlling force production [5], making it so when the limbs act together, they show more control than just the dominant on its own.

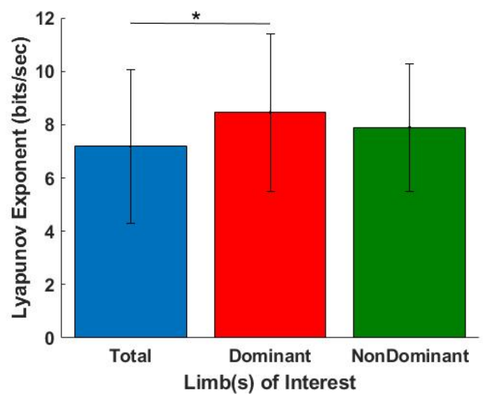

Figure 1: Bar chart of Lyapunov Exponent during the leg press task. *p=0.001

CONCLUSIONS

This study demonstrated that healthy individuals have similar force control between dominant and nondominant limbs during a clinically relevant knee flexion/extension task.

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Table 1: Descriptive statistics of Lyapunov Exponent during the leg press task. *p=0.001

Measure	Lyapunov Exponent (bits/sec)	
	Mean±Standard Deviation	95% Confidence Interval
Total*	7.185±2.880	5.523-8.848
Dominant*	8.457±2.959	6.479-10.166
NonDominant	7.902±2.394	6.519-9.284

ALTERED MUSCLE COORDINATION PATTERNS AFTER THE HIP ABDUCTOR FATIGUE DURING SINGLE-LEG LANDING

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Presentation Preference: **Poster**

INTRODUCTION
Hip abductor fatigue has been shown to increase the risk of ACL injuries during dynamic tasks such as cutting and landing. Previous research has indicated hip abductor fatigue increases hip adduction which may result in an increased knee abduction angle and moment, ultimately leading to an ACL injury [1]. Conversely, other studies investigating hip abductor fatigue have shown little to no change in lower extremity landing mechanics[2]. This may be the result of other muscles compensating for hip abductor weakness by using altered muscle coordination.
Electromyography (EMG) can be used to study muscle coordination during dynamic tasks. However, traditional EMG analysis is limited to muscle activation and muscle activation timing. Wavelet analysis provides a way to simultaneously study the timing, frequency, and magnitude of muscle activation, which could lead to a better understanding of muscle coordination patterns during single-leg landings after hip abductor fatigue [3]. Therefore, the purpose of this study was to identify changes in lower extremity muscle activation patterns during single-leg landings after hip abductor fatigue using wavelet analysis.

METHODS
Ten healthy adults participated in this study (5 females, age 26.6 ± 1.35 years; height 1.75 ± 0.7 m, mass = 71.1 ± 14.1 kg). Three dimensional marker position data were collected at 200Hz using a 3D motion capture system while the participants were performing single-leg drop landings with their dominant leg from a height of 45 cm onto a force platform. Each participant performed single-leg drop landings in pre and post hip abductor fatigue conditions until they achieved 3 trials of single-leg landings for each condition. The fatigue protocol included 3 sets of side-lying hip abduction movements to induce hip abductor weakness. EMG data were obtained from 8 muscles: gluteus maximus, gluteus medius, rectus femoris, vastus medialis, biceps femoris, gastrocnemius, peroneus longus, and tibialis anterior, and signals were analyzed from initial contact to maximum knee flexion. Wavelet analysis was used to resolve EMG signals into time-frequency space. This analysis included 11 non-linearly scaled wavelets with center frequencies ranging from 6.9 Hz to 542 Hz. Total intensity was calculated by summing the intensities for each center of frequency over time.

RESULTS AND DISCUSSION
There were significant decreases in total intensities of vastus medialis, medial gastrocnemius, gluteus maximus, peroneus longus, and tibialis anterior after the hip abductor fatigue protocols. After fatiguing the hip abductors, we found more prominent decreases in vastus medialis and medial gastrocnemius recruitment at medium to high wavelet frequencies. Considering the role of the gastrocnemius and vastus medialis in stabilizing the knee joint, decreases in muscle activation in both muscles may not be desirable during dynamic tasks such as single-leg landings. In general, the total intensity of lower extremity muscles is compressed toward lower to medium frequencies during single-leg landing trials.

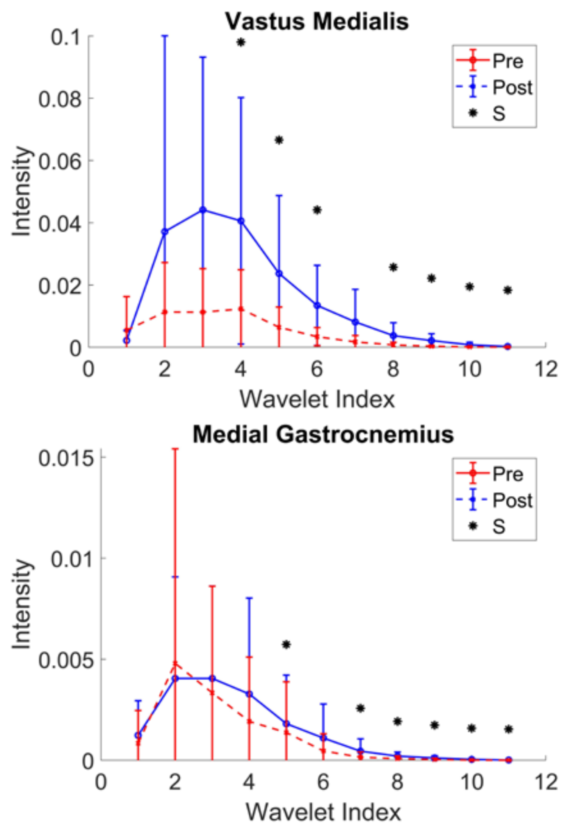

Figure 1: Total intensity for the vastus medialis and medial gastrocnemius pre and post hip abductor fatigue during single-leg landings.

CONCLUSIONS
After hip abductor fatigue, we found altered muscle coordination patterns during single-leg landings. We need to analyze data further to enhance the understanding of muscle coordination patterns after hip abductor fatigue protocols during single-leg landings.

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Validation of Simultaneous, Double-Limb Slips in Younger and Older Adults

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Presentation Preference: [**Poster, Doctoral Student**]

INTRODUCTION

Falls are the second leading cause of accidental death in older adults, and account for 17 million serious injuries worldwide, e.g. bone fractures, head trauma, and bruises[1]. Slips alone account for 25% of overall falls[2]. Traditional fall prevention exercise interventions peak at 30% reduction in falls[3] possibly due to lack of transfer to motor tasks such as trips and slips. Slip training has been previously addressed and shows high promise in reducing falls during slips in the short (1-week) and long term (12 months)[4]. Yet, such methods still lack two factors: 1) identifying reliable biomechanical variables that predict the causation or prevention of falls; 2) laboratory induced slips that mimic slips in real world environment (e.g. unknown slip time and location, low friction surface, double limb slips). This study aims to describe the specificity of reactive responses to slips in young and older adults using a novel slipping method. We hypothesized that older adults would show more falls and use higher arm swing and trunk flexion compared to young adults.

METHODS

One young adult (26 years; 75 kg, 1.75 m) and one older adult (56 years; 85 kg, 1.71 m) participated in this pilot study as honorary invitees. Participants completed double limb slips that were triggered using an in-lab built Wearable Apparatus for Slip Perturbations (WASP)[5]. The WASP induced slips to both limbs simultaneously while participants walked at a fixed gait speed of 1.3±0.2 m/s on a 10 m walkway. Falls were identified if participants applied more than 30% of body weight to the harness, which was measured using a load cell. Full body kinematics were recorded using a 17-camera motion capture system (Motion Analysis Corp., Santa Rosa, CA) and sampled at 100 Hz. Data from slip onset until the reach of complete stop were analyzed. Anterioposteiror (AP) and mediolateral (ML) Margin of stability (MOS)[6] were used to analyze dynamic stability. Peak arm swings and trunk angles were compared between young and old. Relative AP velocity of the two sliding feet was measured to quantify slip severity. Differences between participants in these each outcome variable was tested using independent t-tests.

When the WASP is triggered, it immediately reduces friction by separating a Teflon sock worn over the participant's shoe from a lubricated outsole. This allows the sock to slide over the lubricated outsole, then continue to slide onto the lab floor. To quantify the potential difference in available friction between sliding over the outsole versus over the lab floor, we measured the Dynamic Coefficient of Friction (DCOF) of the interface of the sock with each surface. We measured the acceleration of an unworn WASP (a_{WASP}) as it slid along a sloped surface of angle θ on either a floor tile surface or a PTFE surface filled with WD-40 oil. The DCOF (μ_k) was then calcualted based on the shoe acceleration measured from release until impact with the floor.

$$\mu_k = \frac{g \sin\theta - a_{WASP}}{g \cos\theta}.$$

RESULTS AND DISCUSSION

Older participant showed lower mean AP MOS_{min} (p=0.033) compared to young participant during dominant limb's stance (Table 1). Although arm swing extension may have helped reduce trunk flexion, higher trunk flexion results may explain older adult's inability to rapidly limit trunk motion even with significantly higher arm extension. Such method is directed to help reduce trunk momentum, a typical behavior of fallers[7], which may be the factors associated with a near fall and more harness assistance 21% of body weight (BW) compared to young participant 0.05% of BW (Table 1). Both participants showed split legs only when slips were triggered at heel off; feet velocity moved in opposite directions in the AP (negative is opposite to the walking direction) and in similar directions in the ML (Table 1).

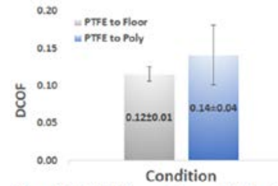

Figure 1: DCOF differences between PTFE to Floor and PTFE to PLY. Error bars represent SD.

PTFE to floor showed slightly lower DCOF compared to PTFE to PLY (figure 1), but both are significantly lower than a typical shoe/floor interface μ=0.4-0.5. Results explain that fluid viscosity increases friction, since shoe to Poly-sheet tile with no oil showed DCOF=0.13. Regardless, there were no significant differences between the shoe and the floor which indicates that transitioning from the Poly sheet to the floor after slip trigger does not reduce slip severity, rather slightly increases it.

CONCLUSIONS

Findings indicate that our novel method is a valid tool in disrupting dynamic stability in both legs for younger and older adults, but older adults may be more prone to falls since they showed lower MOS_{min} and higher harness load assistance. Such limited reactive response could be due to inability to quickly limit trunk motion despite exhausting arm swings to reduce trunk momentum.

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ACKNOWLEDGEMENTS

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Table 1: Kinematic and Kinetic Findings

Groups	Max Harness Ass. (% BW)	MOS_{min} (cm) Mean ± SD				AP Split Feet Velocity (m/s)				Peak Joint Angles (deg)					
		AP		ML		RHO-LHS		LHO-RHS		Right Arm		Left Arm		Trunk	
		DM*	ND^	DM	ND	RFV	LFV	LFV	RFV	Flex	Ext**	Flex**	Ext^	Flex**	Ext**
Young	0.5%	20±17	11±15	10±8	13±8	-1.28	0.58	-	-	5.0±1.5	56.7±2.3	7.7±2.0	57.7±1.8	19.4±2.6	1.8±1.2
Old	21.91%	4±16	31±14	12±3	19±4	-1.09	1.23	-0.29	0.61	2.6±8.3	100.1±25.5	-2.6±3.3	79.4±16.6	32±1.1	11±1.7

* p≤0.05, **p≤0.01. ^ trend p=0.05-0.15. HO: Heel Off. TO: Toe Off. DM: Dominant leg. ND: Non-Dominant leg. RFV: Right Foot Velocity. LFV: Left Foot Velocity

Shoe-stiffness modification to improve gait in older adults: a feasibility study

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Presentation Preference: [**Poster-Graduate Student**]

INTRODUCTION

Walking is critical to maintain functional independence and participate in activities of daily living. Walking performance is determined in large part by the function of the ankle plantar flexor muscles [1] – muscles that are disproportionately afflicted by aging [2]. Thus, interventions aimed at preserving or restoring ankle function are critical for improving mobility in the elderly population.

During walking, older adults typically produce smaller peak ankle joint moments [3] and consume metabolic energy more rapidly [4]. However, peak ankle joint moments are not solely governed by the plantarflexor muscles, but also via leverage provided by anatomical structures of the foot. The foot provides a mechanical advantage during push-off and affects plantarflexor force transmission, promoting economical locomotion [5]. A prior study from our research group has shown that increasing foot stiffness via carbon fiber insoles [6] can alter this mechanical advantage and enhance ankle moment generation. It is currently unclear whether such shoe-stiffness modifications can enhance the mechanics and energetics of walking in older adults. The purpose of this study was to examine the effects of shoe-stiffness modifications on metabolic energy cost and walking performance in older adults. We hypothesized that walking with higher shoe stiffness would: 1) reduce metabolic energy cost and 2) increase 6-min walk distance.

METHODS

To date, 2 male and 1 female older adults (mass: 76.4±12.4 kg, height: 176±7 cm) participated in this study. All participants were free of surgery (within the past 12 months) and any cardiac, neurological pathologies, or pathological problems (osteoarthritis, bone fractures, etc.). Participants completed three visits: two visits to assess their functional walking capacity (6-min walk test), and one visit to measure lower limb kinetics and metabolic energy cost while walking with and without 2 stiffness of carbon fiber insoles [Low (just standard laboratory shoes; no insoles), Medium (1.6 mm insole), and High (3.2 mm insole)]. Walking speed was controlled for all participants at 1.2m/s.

Visit 1: A 6-min walk test (6MWT) was performed in the Low stiffness (no insole) condition. The 6MWT is a submaximal exercise test that assesses the functional capacity of the cardiopulmonary and musculoskeletal systems involved during walking. We measured the participants' 6MWT using a measuring wheel and a tape measure. **Visit 2:** Participants walked on an instrumented treadmill (Bertec, Columbus, OH) to capture limb kinetics for 6 continuous minutes without any assistance at three different stiffness conditions on two slopes [0° (i.e., level), 5° incline]. Breath-by-breath gas exchange (ParvoMedics, UT) measured the volume of expired gases and using published procedures we quantified net metabolic power [7]. **Visit 3:** Participants repeated the 6MWT using the stiffness modification that had provided the best net metabolic power benefit during Visit 2.

RESULTS AND DISCUSSION

Data thus far displayed a slope-dependent effect of shoe stiffness on metabolic cost of walking (Figure 1A). Comparing Low to High stiffness during level walking, the High stiffness reduced metabolic cost by 2.9% - an improvement that further reduced to 11.7% during incline walking. When walking with the stiffness condition that provided the greatest metabolic reduction during level walking (2 subjects used the High stiffness & 1 subject used the Medium stiffness), the 6MWT distance increased by 3.1% compared to the Low stiffness (Figure 1B).

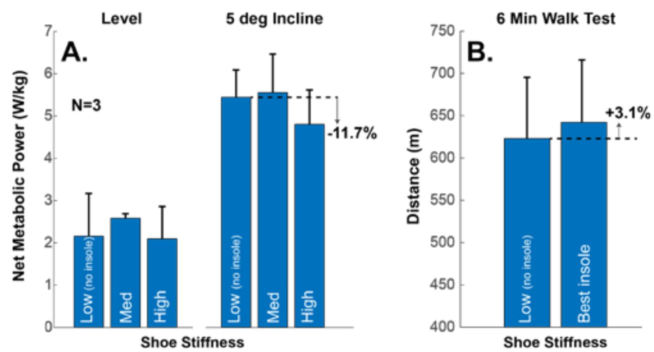

Figure 1: A) Net metabolic power during level and incline walking across three shoe stiffness levels. B) 6MWT distance with and without shoe stiffness modifications.

CONCLUSIONS

This feasibility study provides promising preliminary support that shoe-stiffness modifications can enhance walking performance in older adults. Our continued recruitment efforts into this cost-effective and highly equitable intervention will include analyses of joint-level mechanics and *in vivo* ultrasound measurements of the involved muscles.

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RESPONSE OF MEDIO-LATERAL CENTER OF MASS VARIABILTY BETWEEN LABORATORY AND OUTDOOR WALKING ENVRIONMENTS

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Presentation Preference: **Poster**

INTRODUCTION

Previous literature has reported that environmental factors contribute to an increase in older adult fall risk[1,2]. Medio-lateral (ML) center of mass (COM) Lyapunov exponent (LyE) is a measure of the amount of variability present in postural control and can be used to understand how environmental conditions affect dynamic stability[3,4]. It is well known that dynamic stability, COM LyE, is a measure of balance control, but it is not well known if dynamic stability observed in the literature and in an optimal laboratory environment are comparable to dynamic stability in a daily life environment.

The purpose of this study is to determine the difference between treadmill and environmental conditions on dynamic stability and relate measured dynamic stability to participant self-reported questionnaire measures. We hypothesis that responders will have a greater change in dynamic stability between the Fixed Speed Treadmill (FST) and outdoor (OUT) conditions with no significant change between the Adaptive Speed Treadmill (AST) and OUT conditions while non-responders will exhibit no significant change in dynamic stability between all three conditions. Further we hypothesis that there will be an inverse relationship between the Activities-specific Balance Confidence (ABC) score and Systems Usability Score (SUS) with ML COM LyE.

METHODS

Fourteen older adult participants were included in this study (11 F, 69.43±5.00 years, 1.65±0.10m, 73.05±13.50 kg, 7 Responders, 7 non-responders). Responders were defined as those whose AST self-selected walking speed is closest to their overground self-selected walking speed. Participants were asked to walk on an AST for three minutes at their self-selected walking speed following a two minute acclimation period. Participants were also asked to walk on a FST for three minutes at their self-selected walking speed. The AST and FST conditions were randomized. For the OUT condition, participants were asked to cover as much distance as possible, at their preferred speed for a duration of six minutes. The OUT condition was conducted in a nearby park following a paved circular route. A wireless inertial sensor (IMU) based motion capture system was used to measure COM accelerations during all three conditions. Participants were also asked to complete the SUS and ABC scale questionnaires.

The IMU pelvis sensor accelerations were used to calculate COM variability in the ML direction. Pelvis sensor accelerations from all three conditions were filtered using a 2nd order 20Hz lowpass Butterworth filter. A maximum Lyapunov Exponent analysis was then performed using Wolf's algorithm to calculate ML COM variability. The SUS scale was scored in reference to the AST condition only. All analyses were performed in Matlab. A repeated measures ANCOVA was performed comparing ML COM LyE from AST, FST, and OUT conditions to the responder and non-responder participant groups. Participant self-selected walking speed from each condition was used as the covariate. Four Pearson correlations were performed comparing ABC score to ML COM LyE for each condition and comparing SUS score to ML COM LyE for the AST condition. Statistical analyses were performed in SPSS with significance set to $p \leq 0.05$.

RESULTS AND DISCUSSION

There is no statistical significant difference between FST, AST, and OUT conditions on ML COM LyE for both the non-responder and responder groups. However there is a trended greater change in ML COM LyE between the FST and OUT conditions for the responder group than the change between FST and AST conditions which trended the least amount of change.

There is no significant relationship between ML COM LyE for each condition with ABC score. There is also no significant relationship between ML COM LyE for the AST condition with SUS score. Our results, while not concurrent with previous literature trend in support of hypothesis. A limitation of this study is a small sample size. There are trends in the data which may become significant at larger sample sizes.

Table 1: Mean±SD for Medio-lateral center of mass LyE.

Group	FST ML COM LyE	AST ML COM LyE	OUT ML COM LyE
Responders	30.44±11.92	24.25±14.84	16.25±8.64
Non-responders	24.67±10.37	29.89±8.32	18.55±10.28

CONCLUSIONS

Environmental conditions potentially have an effect on the ML COM LyE such that the use of an AST could be used in studying approximate daily life dynamic stability within a laboratory environment.

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OPTIMAL CENTER-OF-MASS ASSISTANCE TIMING DOES NOT COINCIDE WITH PROPULSION

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INTRODUCTION

Studies from Gottschall and Kram [1] and others [2,3] show that the metabolic cost of walking can be reduced by up to 47% using an elastic tether that provides constant forward forces at the waist. Optimal aiding forces at the center of mass (COM) reduced propulsion at the expense of increasing braking ground reaction forces (GRF). It was suggested that a future research direction could involve developing devices that allow assisting specifically during propulsion. The present study investigated the effects of different, forward force profiles at the COM during walking. We hypothesized that horizontal force profiles that coincide with the propulsion phase would reduce propulsion GRFs.

METHODS

We developed a robotic waist tether that allows applying desired cyclic force profiles at the COM as a function of step time from our cable actuation system robot [4,5] (HuMoTech, Figure 1). Ten healthy participants walked on a treadmill at 1.25 $m \cdot s^{-1}$.

Figure 1: Experimental setup.

A controller was developed that applied 32 sinusoidal force profiles with a desired onset timing and duration (as a function of step time) and a desired minimum force and peak force magnitude. We measured the GRF of both legs using a split-belt treadmill (Bertec). A tension load cell (Futek) measured the tether forces. We assessed metabolic rate by means of indirect calorimetry (Cosmed).

RESULTS AND DISCUSSION

Both horizontal force profiles that coincided with the propulsion phase as well as force profiles that coincided with the braking phase reduced propulsion GRFs (Figure 2). However, contrary to our hypothesis, we found that the metabolically optimal actuation profile did not coincide with the propulsion phase. Robotic tether assistance during the transition from propulsion to braking resulted to higher reductions in metabolic rate than assisting during propulsion (Figure 2). Assistance with optimal sinusoidal force profiles could be helpful in gait rehabilitation environments for individuals with limited mobility to improve their physical activity levels and increase their walking speed.

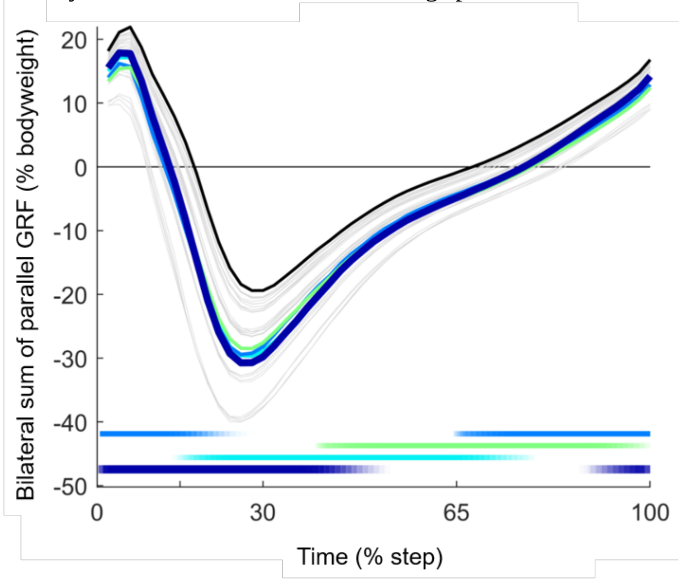

Figure 2: Bilateral parallel GRF. Colored lines indicate the conditions with similar actuation magnitude as the condition with the highest reduction in metabolic rate. The black line is the zero force condition. Gray lines indicate all other conditions. Thick dark blue line marks the condition that had the highest metabolic rate reduction. Horizontal lines show the actuation periods corresponding to each color.

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LOCOMOTOR CONTROL IN PEOPLE WITH PARKINSON'S DISEASE: STRIDE-TO-STRIDE RANDOMNESS INCREASES DURING DUAL-TASK WALKING

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Presentation Preference: **Poster**

INTRODUCTION

With Parkinson's Disease (PD), walking is not automatic but becomes a cognitive task and requires attention[1]. Walking automaticity is typically assessed when people walk while performing a secondary task[2] (dual-task walking), but measures of walking automaticity during normal walking are desperately missing.

In this study, we tested the hypothesis that stride-to-stride variations reflect the degree of walking automaticity. Our main hypotheses were that stride-to-stride variations would be more random with PD compared to healthy elderly (HE), and in dual-task conditions for both groups.

METHODS

Twenty-five people with PD (68± 4.2) and nineteen HE (71± 6.3) went through three 10-min conditions in random order: 1) listening to an audiobook, 2) walking over-ground at their preferred speed, and 3) walking while listening to an audiobook. Cognitive performance was assessed by asking participants to perform a word monitoring task and answering questions about the story after the trial. Gait was measured with instrumented insoles. Stride-to-stride variations were assessed with the detrended fluctuation analysis (DFA), where values closer to 0.5 reflect greater randomness[3].

RESULTS AND DISCUSSION

Our hypotheses were confirmed: stride-to-stride variations were more random in the PD group ($F(1,41)=4.906$, $p=0.032$, $\eta^2=0.107$), and decreased from single to dual-task walking for both groups ($F(1,41)=12.202$, $p=0.001$, $\eta^2=0.229$) (Figure 1). This increased gait variability in the PD group suggests that DFA may reflect gait automaticity. In contrast, there was no group difference for cognitive performance.

There was a positive correlation between change in DFA and performance on the dual-task word monitoring ($r=0.430$, $p=0.032$), and dual-task performance on the context questions ($r=0.471$, $p=0.017$). In other words, participants with more random variations in dual-task walking also performed worst on the cognitive tests, suggesting they may have prioritized gait over cognition.

We also did a sub-analysis of the PD group (early-PD, H&Y<2; mid-PD, H&Y>2). We found that in dual-task walking, DFA decreases only in early-PD but increases in mid-PD ($p=0.043$). Mid-PD also tend to perform better than early-PD at the cognitive task during dual-task walking compared to single-task ($p= .017983$). We found that both groups increase stride time CV and walk slower. Early-PD gait seems to become less automatic in dual-task, and the attention might be directed more toward gait. In contrast, mid-PD may shift their attentional focus and cortical resources more toward the cognitive task (as evidenced by an increase in performance), which in turn leads to less cortically-driven locomotor control.

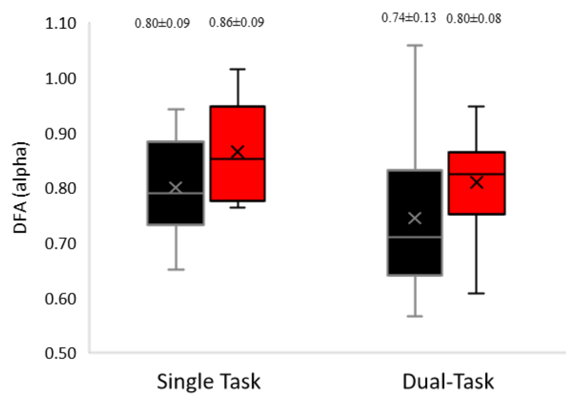

Figure 1: Stride-to-stride randomness for the PD group (black) and control group (red).

CONCLUSIONS

Stride-to-stride variations may be an indicator of walking automaticity, that can be measured outside of dual-task settings. Future studies are needed to confirm this hypothesis, notably by using neuroimaging and instructing participants to prioritize the locomotor or cognitive task.

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SLIP CONTEXT INFLUENCES EXPERIENCED SLIP MECHANICS DURING TURNING

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Presentation Preference: **Podium (Please consider for Promising Graduate Student Award)**

INTRODUCTION

A vast amount of task-specific fall prevention literature has focused on perturbations that occur during straight, level walking. While this is the logical place to start, successfully maneuvering through the world requires a diverse repertoire of locomotor behaviors. Turning, for example, is a very common sub-task of gait, characterizing 35-45% of our daily steps [1]. The biomechanical demands of changing direction are distinct from those of straight, level walking, particularly in muscle activation patterns [2], shear ground reaction forces [3], and friction requirements [4]. Turns themselves are diverse, given the variety of obstacles and paths we encounter. To our knowledge, the impact of slip context, or the initial conditions present when a slip begins, on the mechanics of the resulting slip during a turn has yet to be investigated. Therefore, the aim of this study was to determine how certain contexts, such as the timing of slip onset, slipped foot, and turn radius, influence experienced slip mechanics.

METHODS

18 young adults (22.72±2.89 yrs., 1.73±0.09 m, 72.25±12.35 kg, 9 females) were consented to participate in the following study. All subjects were fitted with a compression suit, safety harness, standardized athletic shoes, full-body marker set, and pair of Wearable Apparatus for Slip Perturbations (WASP) [5]. Subjects were instructed to follow either a 1.0 m or 2.0 m radius, 180° turn with the inside foot relative to the turn at a self-selected comfortable speed. After a time between 30 seconds and 3 minutes, a WASP device was triggered to elicit a slip during early (ES, 0-33%), mid (MS, 34-67%), or late (LS, 68-100%) stance phase of the targeted limb (i.e. inside or outside relative to the turn). Subjects were given a seated rest period after each trial, during which the activated WASP was reset. This protocol was repeated 12 times to expose subjects to all possible condition combinations (3 stance phases x 2 feet x 2 turns). Trial orders and durations were randomized before each session. All trials were recorded by a 17-camera motion capture system at 200 Hz.

Zeni's coordinate-based method [6] was used to determine heel contact and toe-off events. Actual slip onset phases were defined as the percentage of stance that the slipped foot's horizontal velocity began to increase after WASP activation, while slip cessation was taken as either the next velocity minimum or toe-off, whichever happened first. Slip directions were calculated in a CoM reference frame relative to the walking direction at slip onset. Peak slip velocities between slip onset and cessation were derived relative to the CoM, while slip distances represent the absolute displacement of the sliding foot between the same events.

Linear mixed effects models were created to examine the influence of slip onset phase, perturbed foot, and turn radius on slip mechanics, and evaluated with adjusted coefficients of determination. The three aforementioned variables were entered as fixed effects, while subject was entered as a random effect to account for the repeated measures design. ES slips, outside foot slips, and 1.0 m radius turns were baseline predictors in all models. The critical alpha for all analyses was $\alpha=0.05$.

RESULTS AND DISCUSSION

Of the 216 attempted slip perturbations, 139 successful, complete trials were analyzed. All three models were significant predictors of their respective slip attribute (Table 1). Slip directions were significantly influenced by perturbed foot ($t(132)=-6.03$, $p<0.001$) and slip onset phase (MS: $t(132)=3.97$, $p<0.001$; LS: $t(132)=4.79$, $p<0.001$). Slip distances were also significantly impacted by perturbed foot ($t(132)=-2.81$, $p=0.006$) and LS slips ($t(132)=-4.00$, $p<0.001$), but not MS slips ($t(132)=-1.49$, $p=0.139$). Peak slip velocities were only influenced by perturbed foot ($t(132)=-2.06$, $p=0.041$). No attribute was shaped by turn radius (Direction: $t(132)=1.89$, $p=0.061$; Distance: $t(132)=0.77$, $p=0.444$; Velocity: $t(132)=0.11$, $p=0.911$).

Table 1: Adjusted coefficients of determination, F-statistics, and associated p-values for the linear mixed effects models.

Slip Attribute	Adjusted R^2	F(6, 132)	p-value
Slip Direction	0.6480	45.64	<0.001
Slip Distance	0.3169	6.9382	<0.001
Peak Slip Velocity	0.2438	2.3086	0.038

CONCLUSIONS

Turning slips are highly dependent on which foot relative to the turn is perturbed and when the slip occurs during stance phase. Turn radius did not influence slip mechanics, but this may be a result of allowing subjects to walk at a self-selected speed. These outcomes illustrate the role of slip context on the destabilizing mechanics that must be overcome to prevent a fall, and suggests that task-specific fall prevention should use a range of slip types to maximize ecological validity.

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Inter-limb coordination changes during passive exoskeleton-assisted gait is due to spring-loaded assistance but not device weight

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Presentation Preference: [**Poster**]

INTRODUCTION

Healthy walking requires smooth coordination between the two legs, but diseases like stroke impair this healthy coordination. Gait assistive devices, like exoskeletons, have potential to restore healthy coordination between the legs during walking in those with coordination deficits. In our previous study, it was shown that walking with unilateral passive exoskeletons led to a reduction in the duration and the repeatability of inter-limb coordination [1]. However, it was not clear if this reduction was due to spring-loaded assistance provided by the device or merely its weight on the individual.

Therefore, the aim of this study was to examine whether the changes in coordination was due to passive assistance or due to the weight of the device. Specifically, we investigated how the duration and repeatability of inter-limb coordination was altered when a group walking with unilateral passive exoskeleton assistance were compared with a group walking with a unilateral ankle weight and a control group with no assistance or weight.

METHODS

In this study, 24 young healthy individuals were recruited. Each participant was placed into one of 3 groups: Passive exoskeleton on the right leg (EXO: = 9), No exoskeleton, control group (NOEXO: N = 9), and unilateral limb loading on the right leg (ULL: N = 6). All participants performed 5 minutes of walking at their preferred walking speed. For those in the EXO group, participants wore a passive exoskeleton on their right dominant leg [2]. This device provide assistance to the wearer during the swing phase. The weight of the device was 7.5 lbs. For the unilateral limb loading group, the ankle weight was matched to the weight of the passive exoskeleton.

Inter-limb coordination was examined using nonlinear tools, specifically, cross-recurrence quantification analysis (cRQA) and cross-sample entropy (cSE) by examining the relationship between the left and right heel marker position in the anterior-posterior direction. For cRQA, the mean diagonal length was one of the main outcomes [3]. For cSE, vector length was set to 3 with tolerance of 0.25 [3]. Statistical difference was examined via one-way ANOVA (p<0.05), and further analyzed with post-hoc analysis.

RESULTS AND DISCUSSION

The duration of coordination, quantified by mean diagonal length, showed a significant group effect. Further analysis via post-hoc test revealed that the NOEXO group had a significantly (p<0.001) longer mean length (9.68±0.68) than the EXO group (7.48 ±1.41) but was not different from the ULL group. This indicated that the altered inter-limb coordination through passive exoskeleton-assistance was not because of its weight. In addition, there was no significant difference between the groups for cSE value. This indicated that exoskeleton-assistance does not disrupt the natural regularity of inter-limb coordination (Figure 1).

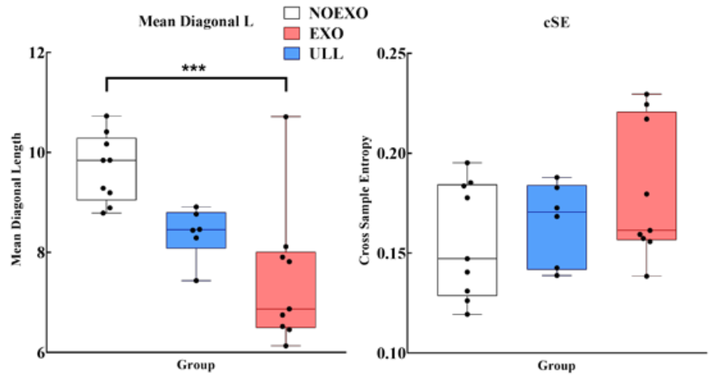

Figure 1: The average diagonal length from the cRQA and the average entropy value from the cSE in the three groups. Significance of p<0.001is indicated by ***.

CONCLUSIONS

An unpowered exoskeleton that assists the swing phase of gait reduced the duration of inter-limb coordination and this effect was due to exoskeleton assistance and not the weight of the device. This shows that the potential of exoskeletal devices to restore disrupted inter-limb coordination in those with coordination deficits.

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DEVELOPMENT OF LOW COST 3D PRINTED ACETABULAR FRACTURE MODELS FOR SURGICAL PLANNING

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

INTRODUCTION

Over the last 30 years, 3D printing has had a large impact within the field of medicine. The most common uses have been to produce anatomical models to replicate internal structures for surgical planning, implant creation, and clinical education [1]. The development of anatomical models has been utilized in a number of operations and has been extremely successful in improving surgery conditions [2]. Across several studies, a number of benefits have been recorded when an anatomical model was incorporated to plan the operation [3]. Often times the models used for surgical planning are too expensive for most hospitals to develop regularly. There is little research investigating differences between production methods, which could significantly reduce the cost per model [4].

The goal of this study was to develop anatomical models using different segmentation and printing methods to verify accuracy at representing the region of interest and potential utility as a method of pre-surgical planning for orthopedic surgery. Five acetabular fracture models were developed using FDM and SLA/Resin based printing methods and evaluated based on their accuracy in representing the region of interest.

METHODS

Five pelvic models with acetabular fractures were developed using four different printers (total of 20 models). Models were 3D printed on a variety of high and low-cost printers as well as segmentation software types to assess differences between the production methods (Fig. 1). In order to assess the printed models' precision in replicating the correct size of the patient's pelvic bone, the distance from the posterior inferior iliac spine to the ischial spine was recorded from the CT scan and compared to physical measurements taken directly on the 3D printed models. Additionally, a unique fracture fragment was also measured directly on the CT imaging data and then compared to physical measurements taken directly on the printed models. The mean measurement error values were analyzed using one-way ANOVAs with $\alpha = 0.05$.

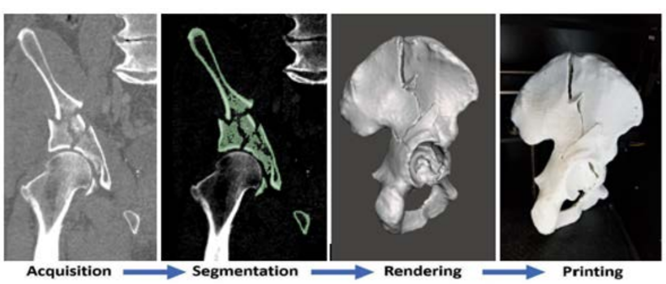

Figure 1: Customary steps in anatomical model development.

RESULTS

Significant differences were found on the model's representation of the acetabular fracture on the physical measurements, $p = 0.007$ (Figure 2). The results of the Bland-Altman analysis show that there is a general agreement between the measurements recorded from the different methods of model development (Figure 3).

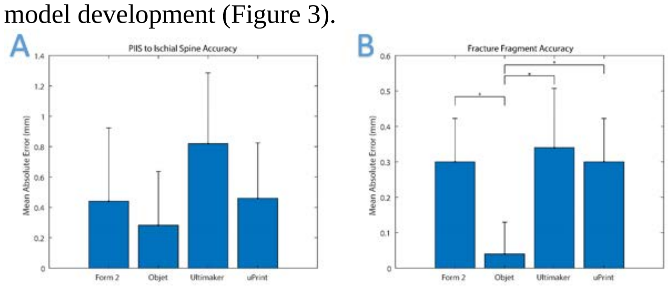

Figure 2: Mean absolute measurement error for A) the distance between the posterior inferior iliac spine and ischial spine and B) the fracture fragment distance. Significant differences are denoted by *.

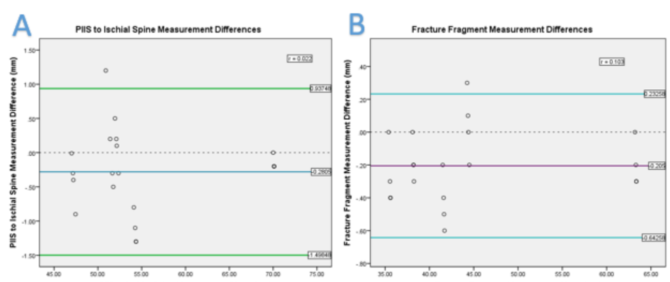

Figure 3: Bland-Altman analysis of the measurement error for A) the distance between the posterior inferior iliac spine and the ischial spine and B) the fracture fragment distance.

DISCUSSION

It is likely that anatomical models developed at any price point will be sufficient in providing some level of improved conceptualization. However, the results from this research indicate slight differences likely exist as a result of the method used to develop the model. The question of the clinical relevance of this difference requires further investigation.

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DUAL-TASK PRIORITIZATION DURING OVERGROUND WALKING: SINGLE CASE RESULTS

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Presentation Preference: **Poster**

INTRODUCTION

Our group has previously shown that during dual-task walking [1], stride-to-stride variations become more random in people with PD and healthy older adults. We also found that participants with more random variations in dual-task walking compared to single-task walking did not perform well on the cognitive task during dual-task walking. This result suggests that stride-to-stride randomness [2] may be a marker of gait automaticity, where greater attentional control of gait correlate with more random variations. This study aims to test this hypothesis, by comparing dual-task walking with and without task-prioritization. We expect randomness to decrease when participants are instructed to focus on the cognitive task, and conversely, we expect that prioritizing the locomotor task will increase randomness of stride-to-stride variations.

METHODS

This project is part of a longitudinal study comparing PD patients and healthy older adults. Due to the COVID-19 situation, only one healthy older adult (78 years old female) completed the following protocol. After providing signed informed consent, she answered questionnaires and performed some clinical tests to measure cognitive capacity and mobility. She then performed a single cognitive task (STC), and a single walking task (STW) the same day, then came back for a second visit to perform three dual-task walking conditions with no prioritization (DT), prioritization on the cognitive task (DTC) or prioritization on the walking task (DTW). For all conditions, she was wearing headphones and had pressure sensitive insoles placed in her shoes. During the STC, the participant listened to 10 minutes of an audio book while being seated. She was tasked with monitoring the number of times two predetermined words occurred, while also paying attention to the plot of the story. The DT condition was assigned, then the two dual tasks with prioritization assigned in random order. For the DT condition, she was only told to walk while listening to the audiobook. In the DTW condition, she was told to focus on her gait with an emphasis on maintaining a constant speed, cadence, and consistent stepping. For the DTC condition, she was told to pay close attention to the audio book while walking with the goal of answering all post condition questions correctly. After each dual-task condition, she was be asked 10 questions about the plot of the story and the number of times two pre-determined words occurred. All walking conditions required the participant to walk in one direction continuously for 10 minutes around a 200-meter track. Stride-to-stride variability collected from insoles was analyzed through the detrended fluctuation analysis (DFA), where values closer to 0.5 reflect higher randomness.

RESULTS AND DISCUSSION

Gait data for the DT condition was not available due to technical issues. There was a decrement in DFA from STW to DTW and DTC (Figure 1), suggesting that stride-to-stride variations were more random while performing both dual-task conditions, contrary to our hypothesis. However, the participant was unable to answer any audiobook questions after the single task cognitive condition. This may suggest that the audiobook was too difficult to follow, that she was not paying enough attention, or that she has some general attentional impairments. She answered correctly 3/10 questions during DT condition, 3/10 questions in DTC condition, and 4/10 questions in DTW. The participant counted 12/13 occurrences of the two designated words in STC condition, 8/11 occurrences in DT condition, 18/15 occurrences in DTC, and 23/18 occurrences in DTW. If confirmed, these results suggest that DT walking lead to more random variations, independently of task-priority, which may have consequences for rehabilitation.

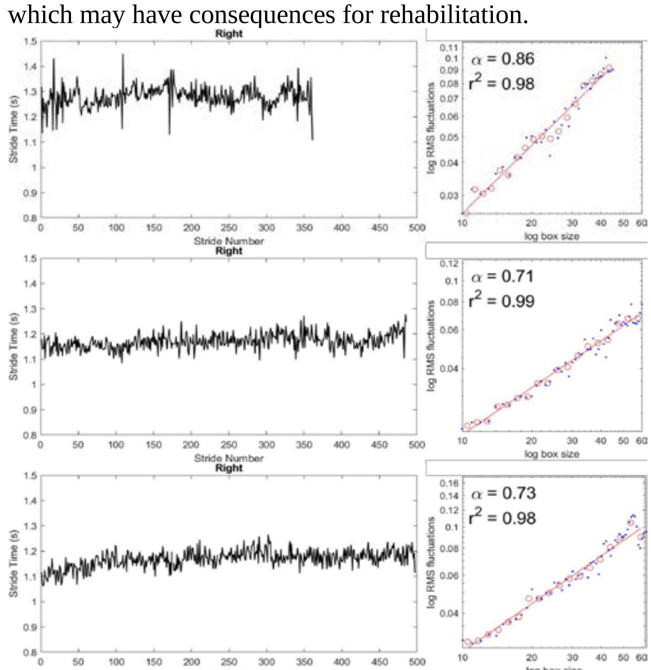

Figure 1: Reduction of DFA from single-task walking (top) to dual-task with prioritized walking (middle) and dual-task with prioritized cognition (bottom).

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KINEMATIC AND KINETIC INVESTIGATION INTO CLEATED VERSUS SHOD RUNNING

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INTRODUCTION

Traditional running shoes are often associated with a rearfoot strike pattern, and high impact forces which can be concerning due to their correlation with injury [2]. Consequently, it is unknown whether the difference in running characteristics is due to the shoes being worn or the conditions in which they are worn. With the rising popularity of minimalist shoes, researchers have examined the injury risks associated with other types of running footwear. Differences in foot strike patterns have been found between habitual runners in traditional and minimalist shoes [1], however this research is still ongoing as barefoot and minimalist running have recently been gaining in popularity. Individuals who wear cleats, which have similarities to minimalist shoes in that they offer little to no support, typically run long distances in traditional shoes as well. The objective of this study was to determine if kinematic and kinetic variables differ between cleated and shod conditions in individuals who habitually run in both. We hypothesized that there would be no differences in the kinematics of running form, but vertical impulse and loading rate would be increased in the cleated conditions.

METHODS

Participants consisted of healthy college-aged ultimate frisbee and soccer players, who were habitual runners in both cleated and shod conditions (n = 18, age = x ± x yr, height = x ± x m, weight = x ± x kg). Participants reported wearing cleats for x ± x years and x ± x hours per week during the season of the study. Subjects were excluded from the study if they had any previous history of ACL tears or any lower extremity injuries in the past year. Using a repeated measures design with a random order of cleated and shod conditions, kinetic and kinematic running variables were analyzed. In each trial subjects were tested while running at approximately 201 $m \cdot min^{-1}$ (7.5 miles per hour) on a foam pad over a rigid indoor surface.

Subjects wore their own shoes in both conditions; no subjects wore minimalist shoes. The trials were completed in one session. Running speed was controlled using electronic timers (Farm Tek) to regulate consistent speeds across trials. The kinematic variables analyzed included: running speed (m/s), step length (m), step rate (steps/min), step time (s), time of support (s), and ankle angle at footstrike (deg). The kinetic variables analyzed included: vertical impulse (BW*s), loading rate (BW/s). The variables were attained by 3D analysis using Vicon Motion Capture Analysis (Polygon and Nexus), ten MX T40-S high speed cameras (100 Hz), two Bonita video cameras (100 Hz), and a Bertec force plate (1000 Hz). Total impulse (N*sec) and loading rate (BW/s) were also analyzed using MATLAB coding. Each kinematic variable was measured at multiple foot strikes which were averaged for statistical analysis. Statistical analysis was performed using paired t-tests with an alpha level of 0.05.

RESULTS AND DISCUSSION

Notably, there were no statistically significant differences between conditions for step length, step rate, running speed, step time, and time of support. For kinetics, a significant difference was found in the vertical loading rate between the cleated and shod conditions (Table 1). The non-significance of dorsiflexion angle at heel contact across conditions demonstrates the consistency of footstrike patterns. Given the non-significance of total impulse, loading rate differences are most likely due to the footwear composition. This is contrary to the expectation that a different shoe influences running technique, which would be thought to have a change in the dynamics of the impact upon ground contact.

CONCLUSION

In light of the non-significance of the gait kinematics, differences in loading rate are most likely due to variation in composition between cleated and shod conditions.

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Table 1: Descriptive statistics and analysis of both cleated and shod conditions

Kinematic Variable	Cleated M±SD	Shod M±SD	p-value	Kinetic Variable	Cleated M±SD	Shod M±SD	p-value
Running Speed (m/s)	3.3956±0.1588	3.4150±0.1647	0.297	Vertical Impulse (BW·s)	471.4±293.9	490.0±338.1	0.785
Relative Step Length (step/height)	0.7360±0.0562	0.7464±0.0767	0.302	Loading Rate (BW/s)	78.87±34.82	53.96±21.61	0.013
Step Rate(steps/min)	165.78 ±10.73	165.39±12.84	0.748				
Step Time (s)	0.36944±0.02775	0.36778±0.03524	0.752				
Time of Support (s)	22.731±1.220	22.917±1.541	0.427				
Ankle Angle at Footstrike (°)	11.21±4.64	12.92±3.73	0.147				

LONGITUDINAL ANALYSIS OF GAIT VARIABILITY AND BRAIN ACTIVITY WHILE DUAL TASKING IN PEOPLE WITH PARKINSON'S DISEASE

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INTRODUCTION

Parkinson's Disease (PD) is a degenerative disease that effects the dopamine-producing neurons of the brain, resulting in tremors, limb rigidity, and gait and balance problems.[1] In the present study, gait and balance problems will be evaluated under the strain of dual-task walking. The introduction of the second task moves key attentional resources away from walking, which can result in an increased risk of falls, especially for older adults with PD.[2] In addition to changing attentional strategies, introducing a second task also increases prefrontal brain activity and increases random variability in walking patterns, which can also lead to an increased risk of falls.[3]

In this present study, three hypotheses are proposed: 1) participants with more random variability will also have higher prefrontal activity; 2) instructing PD participants to focus on the walking task will increase randomness and prefrontal activity compared to when they are asked to focus on the cognitive task; 3) participants who have PD and a higher degree of randomness and prefrontal activity at baseline will be at an increased risk for a fall within a one-year period.

METHODS

The proposed study will include 60 participants with PD and 60 age-matched controls. All participant's gait impairments, brain activity, and falls will be followed for one year across six laboratory visits: two at baseline, two after six months, and two after one-year. For each visit, participants will complete a series of clinical tests prior to being fitted with pressure sensitive insoles, inertial measurement tools, headphones, and a functional near infrared spectroscope (fNIRS).

Participants will first be introduced to the over-ground walking task and an audiobook via the headphones (cognitive task) with no instructed prioritization to one task or the other. Prioritized instructions for diverting attentional resources to the walking task or audiobook task will be randomized following the baseline task. Prefrontal activity will be monitored using the fNIRS, gait randomness will be monitored using the provided insoles and inertial measurement tools. Falls will be monitored using a take-home journal that participants will document falls and near-falls and provide at each visit.

DISCUSSION

The proposed methods aim at understanding how attentional dividing activates the prefrontal cortex and effect gait variability in PD patients. Supportive data for the hypotheses are crucially needed to better understand how PD longitudinally affects gait variability, and to elucidate the relationship between gait variability, prefrontal activity and falls in PD patients. Beyond these important advances for basic scientific knowledge, the results from this protocol will also serve to enhance rehabilitative gait interventions in older adults with PD, such as patient-centered dual-task training with or without task-prioritization based on the patient's individual performance.

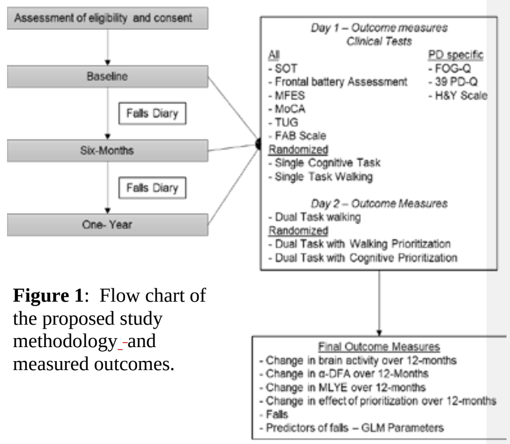

Figure 1: Flow chart of the proposed study methodology and measured outcomes.

CONCLUSIONS

This project will improve the objective assessment of fall risk in PD patients using gait parameters during cognitively challenging conditions, similar to those experienced in patients' daily lives. Identifying people at risk of falls may also lead to the development of individualized interventions to prevent falls.

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MOTOR AQUISTION OF A UNIQUE GAIT PATTERN

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INTRODUCTION

The capacity to acquire new motor skills (e.g. motor learning) is essential in maintaining and regaining movement for individuals with neurodegenerative diseases such as multiple sclerosis (MS) [1]. However, the vast majority of motor learning research in MS has focused on upper limb movements or scaling of pre-existing coordination patterns [2]. To further understand motor learning in MS, we developed a unique walking task, which involved a novel toe-heel strike pattern. Importantly this task requires a new coordination pattern and is functionally relevant. Prior to investigating this task in clinical populations, it is necessary to determine its feasibility in a motor learning context.

The purpose of this study was to benchmark motor learning of this unique walking task in healthy controls.

METHODS

Six young adults (22±3 yrs; 3 male / 3 female) participated. All participants reported having no prior experience of toe-heel walking.

After providing informed consent, participants underwent a series of baseline walking trials across a 20ft Zeno walkway, next they trained toe-heel walking for 2 minutes on a level treadmill, followed by 2-3 minutes of seated rest, and then an over ground toe-heel performance trial. Training and performance trials were repeated 8 times. Training speed was determined by 80% of the previous performance speed.

Our outcome measures were normalized performance speed and percentage of correct steps. Performance speed was measured by analyzing Zeno walkway trials using PKMAS software, and was then normalized to individuals' maximal walking speed. Correct steps were determined by foot strike center of pressure location data from PKMAS software, and analyzed with a custom algorithm in MATLAB to determine correct steps [Fig 2]. Correct steps were then calculated as a percentage of total steps. We used one-way repeated-measures ANOVA to compare performance speeds and correct steps over the duration of training.

RESULTS AND DISCUSSION

Across the duration of the training, there was a significant increase in toe-heel walking speed [$F(1.7, 8.4) = 10.8$, $p = .006$; Fig. 1]. Furthermore, pairwise comparison identified that there was an increase from 41% of fast heel-toe walking speed at baseline to 81% after training ($p < .005$). There was no significant change in the percentage of correct steps across performance trials [$F(2.4, 11.9) = 2.03$, $p = .170$].

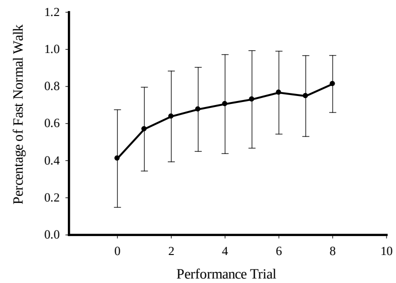

Figure 1: Represents young adults' toe-heel walking speed from baseline to post-training. Normalized to individuals' fast toe-heel walking speed. There was a significant increase in performance across trials ($p < .05$)

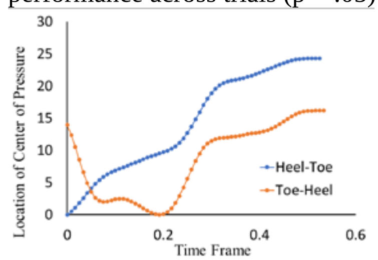

Figure 2: Represents center of pressure (COP) location during a single step. Heel-toe steps follow a linear trend, while toe-heel steps follow a quadratic trend. A custom MATLAB algorithm was applied to determine correct steps as a toe-strike to heel-strike to toe-off pattern, based on the COP location.

CONCLUSIONS

Participants performed the toe-heel foot strike pattern proficiently throughout the entire training session (85% at baseline to 92% by post-training). Most notably, participants improved their walking speed by ~40%. Toe-heel walking is a novel walking pattern, which initially requires an attentional demand, but is only a slight alteration to the degrees of freedom of normal walking. Based on the simplicity of tasks and relevance to daily settings, we believe our methodology for toe-heel walking training and evaluation can be advantageous for studying motor learning in clinical populations, such as older adults and people with neuromuscular disorders.

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