Split belt walking increases Neurovascular Response during Gait Coordination Task in Stroke

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The purpose of this project was to analyze the neurovascular responses of Stroke survivors provided during split belt treadmill adaption by using. In this ongoing study, ten chronic stroke survivors walked on an instrumented split-belt treadmill while being exposed to different belt speeds for each leg. The affected leg was on the fast/slow belt if its stride length was shorter/longer than the less affected side respectively. Functional near-infrared spectroscopy was used to measure hemodynamic changes in the cerebral cortex. We determined the changes in neurovascular responses due to immediate learning, late learning of split belt paradigm and transfer effects of split belt training to tied belt condition. Changes in mean Oxyhemoglobin values were determined from filtered data in regions of interest.
There was significant main effect of split belt condition on changes in Oxyhemoglobin concentration in the supplementary motor area ($p=0.007$) and post central gyrus ($p=0.008$). Post-hoc analysis revealed significant decrease in change of Oxyhemoglobin concentration from late learning to transfer stage in the supplementary motor area ($p=0.033$). This indicates a higher neurovascular response in our group of Stroke survivors due to split belt protocol. Specifically, changes were observed in the planning and execution of the motor learning task.

Spatiotemporal gait parameters are affected by footwear stiffness in toddler-aged children.

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Footwear plays a significant role in, and can influence children's gait. Footwear type is especially important as a child grows and develops from a novice to an expert walker. Compared to barefoot walking, children generally have increased spatiotemporal (ST) gait parameters while walking with footwear. Gait variability has also shown to be affected by footwear. The degree of stiffness in footwear could have a large influence on children's gait and variability. This study investigated effects of footwear stiffness on ST gait parameters and gait variability (Standard Deviation (SD) and Coefficient of Variation (COV) in novice walkers. Children with an average age of 33.3 (± 7.0) months participated in a single data collection. Participants were acclimated to the treadmill while a self-selected comfortable walking speed was determined. Heel and toe marker positions were acquired for one minute of walking per condition using motion capture software. Participants walked on the treadmill wearing footwear with three levels of stiffness (rigid: hard-soled stiff shoe, semi-rigid: EVA sole athletic shoe, compliant: moccasin soft-sole shoe) and barefoot. ST gait parameters and gait variability were calculated for each condition. Stride length, step length, stride time, step time, stance time, and swing time all increased in the rigid and semi-rigid footwear conditions compared to soft-sole and barefoot. Interestingly, there were no differences between barefoot and wearing a moccasin for any of the ST variables. There were no differences in SD and COV between any of the footwear conditions. The moccasin shoe promotes walking most similar to normal barefoot walking, as evidenced by the agreement between ST variables. The moccasin shoes may allow a more natural flow of proprioceptive information while providing protection for the feet. Standard measures of variability failed to detect differences between footwear conditions. Further investigation into different methods is necessary to parse out what effect footwear has on children's gait variability.

RANGE OF MOTION AND WALKING DISTANCES IN SUBJECTS WITH PERIPHERAL ARTERY DISEASE

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Peripheral artery disease (PAD) is a consequence of atherosclerotic blockages in the lower extremity arteries that results in gait dysfunction and muscle pain known as claudication. Gait variability has emerged as an assessment or function and risk factor for falls in older and pathological groups[1]. A healthy gait pattern demonstrates stride-to-stride fluctuations within a certain range of values.[2] This study measured variability using linear measures of variability which include standard deviation (SD) that provides the magnitude of variability present in the time series around a central point, namely the mean, and coefficient of variation (CV). The overall goal of this project is to look at improvements in range of motion (ROM) variability baseline to post-surgery. Thirty nine subjects were recruited from the Veteran's Affairs Medical Center after being evaluated by vascular surgeons and meeting the inclusion criteria. The setup will include subjects walking on the treadmill while kinematic data is collected using a twelve-camera motion capture system (Motion Analysis Corp, Santa Rosa, CA). Specifically, three-dimensional kinematics of patients walking on a treadmill will be acquired at 60 Hertz using Cortex software (Motion Analysis Corp, Santa Rosa, CA). The subject will walk on the treadmill until the first sign of pain, recorded as initial claudication distance. For the graded treadmill test subjects were walking at two miles/hour, with a two% increase every two minutes. The distance of maximum pain the subject can handle is called absolute claudication distance. Marker position data will be analyzed using MATLAB (Mathworks, Inc., Natick, MA). The dependent variables calculated included: mean ROM, SD ROM, CV ROM, six minute walking distance, ICD, and ACD. Dependent t-tests will be used to compare baseline ROM with post-surgery walking distances. Significant differences between mean ROM, SD ROM, and CV ROM at baseline and post-surgery six minute walk distance, ICD, and ACD values were found. Lack of functional training may prevent improvement of walking patterns and it may be necessary to include rehabilitation with functional exercises following surgical revascularization in patients with PAD.

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PATIENTS WITH COPD THAT REPORT MUSCLE FATIGUE, INSTEAD OF BREATHLESSNESS, HAVE REDUCED ANKLE KINETICS

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INTRODUCTION

Chronic obstructive pulmonary disease (COPD) is a condition that not only affects the lungs but can also manifest as skeletal muscle abnormalities including weakness, reduced muscle metabolism, and muscle fatigue [1]. The progressive nature of the disease presents a spectrum of varying severity of symptoms. Current COPD measures allow for classification into stages of COPD based on FEV1/FVC ratio and the more encompassing BODE index [2,3]. Separating subjects into groups based on lung capacity only, may not adequately measure COPD limitations. For instance, those with functional limitations, particularly within the peripheral systems may have more difficultly within everyday tasks than those with average muscular function. Subjective measures of gait abnormality, e.g. reported limps and shuffles, are related to severity [4].

Roughly 40% of patients with COPD report that their main limitation to physical activity and performance is muscle fatigue and not breathlessness [5]. The capacity to participate in physical activity is not increased by improved ventilation in patients with COPD that exhibit muscular fatigue. Muscle performance does not improve with the use of bronchodilators. Muscular fatigue is present in patients with mild to moderate COPD irrespective to lung function, anthropometric data, or quadriceps strength [6].

The purpose of this study was to determine whether two subsets of COPD subjects, those with and without muscle fatigue, have significantly different biomechanical gait function. We hypothesized that patients with COPD characterized with low muscular function would demonstrate less plantarflexion moment and power than those with high muscular function, based on previous findings [7].

METHODS

Seventeen patients with COPD were recruited to participate in this study (age: 63.7±8.55 years, height: 171.91± 11.79 cm, mass: 90.58±25.62 kg). Patients were excluded if they have any previous injury or co-morbidity that would affect their gait pattern.

Gait kinematics (Motion Analysis Corp., Santa Rosa, CA; 60 Hz) and ground reaction force data was collected (Kistler Instrument Corp., Winterthur, Switzerland; 600 Hz) while patients walked at their self-selected pace down a 10-meter walkway under two conditions (REST and NO REST). At first, five trials of the walkway were collected with a minute between each trail (REST). Patients then walked at a self-selected pace on a treadmill until they reported breathlessness or leg fatigue. This was a completely subjective measurement. They then repeated five more trials of walking across the walkway without rest in between (NO REST).

The high muscle function group was defined as the group that reported breathlessness as the limiting factor to walking on the treadmill (n=8). Whereas, those that reposted muscle fatigue as the limiting factor to walking on the treadmill were placed in the low muscle function group (n=8). One subject did not have enough strides for data analysis and was removed from the data. Gait variables calculated included spatio-temporal parameters, kinematic and kinetic variables calculated during stance phase from the five trials of the REST and NO REST conditions for both groups. Data was compared using two-way ANOVA.

RESULTS AND DISCUSSION

No significant findings were found for the REST condition for any dependent variables. In addition, no significant findings were found for any of the spatiotemporal or kinematic variables compared in the NO REST.

During the NO REST condition, the low function group (1.19±0.20 N-m) demonstrated significantly lower peak plantarflexion moment as compared to the high function group (1.44±0.12 N-m) ($p=0.01$) (Figure 1). For ankle power generated, the low function group yielded an average of 2.02±0.77 W while the high function group yielded 2.68±0.27 W ($p=.03$) (Figure 2). Yentes et al. support these findings, in which patients with COPD demonstrated gait mechanics differences in as compared to healthy age-matched controls for ankle plantarflexion moment [7]. However, during that investigation, all disease severities were studied together in one group. In the current study, the separation of those with muscle fatigue and those with breathlessness allow for a more in depth look at the differences within COPD. The group with low muscle function and thus low moment and power may not adequately improve by conventional rehabilitation measures that rely on improving breathlessness.

CONCLUSIONS

Many patients with COPD have muscular fatigue as a major limitation to activity [5]. Although not all those with COPD have similar muscle function issues, determining those that have these increases of muscular weakness may increase the effectiveness of treatment and rehabilitation. Establishing muscular differences within COPD severity may be an important step to establishing appropriate techniques in rehabilitation. The differences between plantarflexion moment and power may be due to an unknown variable not yet researched within the phenotypes of COPD. Further, this study illustrates the possibility of different phenotypes within COPD. Research is needed to determine if such phenotypes exist.

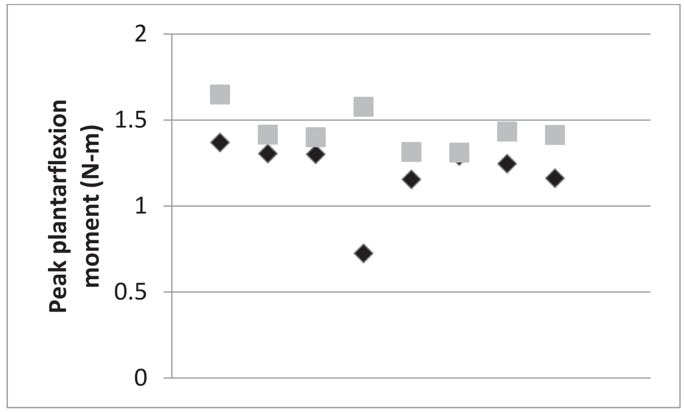

Figure 1: COPD patients with low muscle function (black) demonstrate significantly lower peak moment than those with high muscle function (grey)

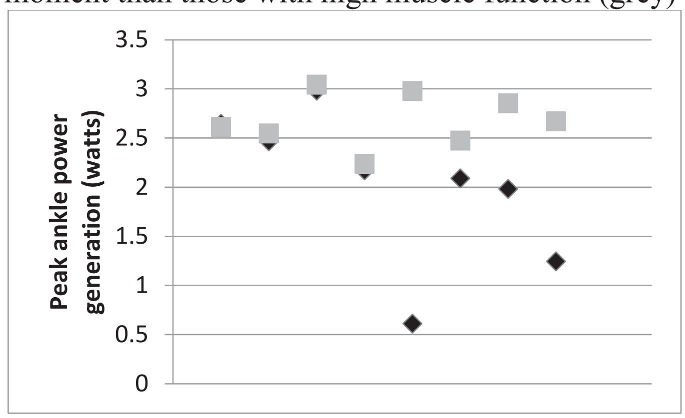

Figure 2: COPD Patients with low muscle function (black), compared to high muscle function (grey), demonstrate significant decrease in peak ankle power generation.

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STITCHING TOGETHER SHORT GAIT TRIALS FOR UNDERSTANDING STRIDE-TO-STRIDE ORGANIZATION OVER TIME

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INTRODUCTION

The organization of stride-to-stride variability is estimated by a scaling exponent α that reveals significant insight about function, and dysfunction, of the locomotor system [1], not provided by standard metrics such as the mean and variance of series of stride-to-stride time intervals. The analysis of the organization of stride-to-stride variability requires continuous recording of a large quantity of stride intervals, e.g. participants walking for 15 to 30 minutes at a constant speed [2]. This requirement becomes a major limitation when investigating research questions for populations such as the elderly or patients with Parkinson's disease (PD). Those subjects might not be able to walk for long enough time due to several factors including fatigue and fear of falling.

Recent evidence [3] suggested that stitching together shorter gait trials to create one longer series of stride time intervals provided similar α-values compared to continuous long gait trial. However, the study did not directly compare 'stitched' time series to continuously recorded time series. Furthermore, the 'stitched' time series were relatively short, approximately 125 stride intervals, compared to the large quantity of stride intervals required for a proper estimation of the scaling exponent α (at least 600 stride intervals, see [2]). Finally, the study only compared patients with PD to healthy young adults but not to age-matched controls, making it difficult to distinguish between the effects of aging and disease. This project aims to address these limits.

METHODS

At this time, only 3 healthy young adults were recruited. The study took place on a 200m indoor track. Participants were instructed to walk at a comfortable and regular speed for the entire session in all conditions, all trials. They performed three conditions, presented in a randomized order: *'15 min'*, e.g. walking for one trial of 15 minutes around the track; *'3 min'*, e.g. walking for five trials of 3 minutes around the track; *'30 sec'* e.g. walking for thirty trials of 30 seconds around the track. Recording started after 10 seconds of practice for each conditions to reduce the effects of gait initiation and acceleration to preferred walking speed. To reduce any affects of fatigue, subjects were provided at least 5 minutes of rest between each condition and at least 30 seconds of rest between each trial for the *'3 min'* and *'30 sec'* conditions.

A footswitch with force sensor was placed under the heel and first metatarsal head of both feet to determine heel-strike and toe-off events. Stride-to-stride time intervals were extracted for further analysis. In the *'3 min'* and *'30 sec'* conditions, the first and last four stride intervals within each trials were removed before concatenation of all trials to obtain 'stitched' time series. To provide a reliable comparison between subjects and between conditions, further analysis considered only the first 500 stride time intervals.

Detrended fluctuation analysis (DFA) was used to estimate α-values. Briefly, the DFA provides an estimation of the size of fluctuations $F(n)$ for each window of observation of size n. The slope of $F(n)$ as a function of n in log-log coordinates corresponds to the scaling exponent α (Figure 1, lower panel).

Future data collection will include individuals with Parkinson's disease as well as age-matched control subjects.

RESULTS AND DISCUSSION

We will only report values from the right heel strikes, as results were very similar between the four footswitches sensors. Mean and standard deviation of stride-to-stride time intervals were very similar between conditions for the three subjects (Table 1). Overall, the α-values were within normal range for this population ($0.8 < \alpha < 1$), but sometimes very different between conditions for the same subject (for example, S02 in *'3 min'* and *'15 min'* conditions, Table 1).

CONCLUSIONS

Our results must be considered with extreme precaution due to the very low number of subjects. The stitching procedure seems to preserve the mean and the standard deviation compared to continuous long trials, but the α-value seems influenced by the procedure. If this trend is confirmed, it might imply that stitching together short gait trials does not provide the same information about locomotor function as continuous long gait trials.

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Table 1. DFA, mean and standard deviation of stride-to-stride time intervals from the three subjects in the three conditions.

	DFA (α)			MEAN (s)			SD (s)		
	30 sec	*3 min*	*15 min*	*30 sec*	*3 min*	*15 min*	*30 sec*	*3 min*	*15 min*
S01	0.99	0.83	0.88	1.078	1.094	1.056	0.016	0.019	0.015
S02	0.93	0.84	0.99	1.026	1.016	1.024	0.022	0.015	0.019
S03	0.86	1.00	0.92	1.054	1.059	1.044	0.020	0.017	0.018

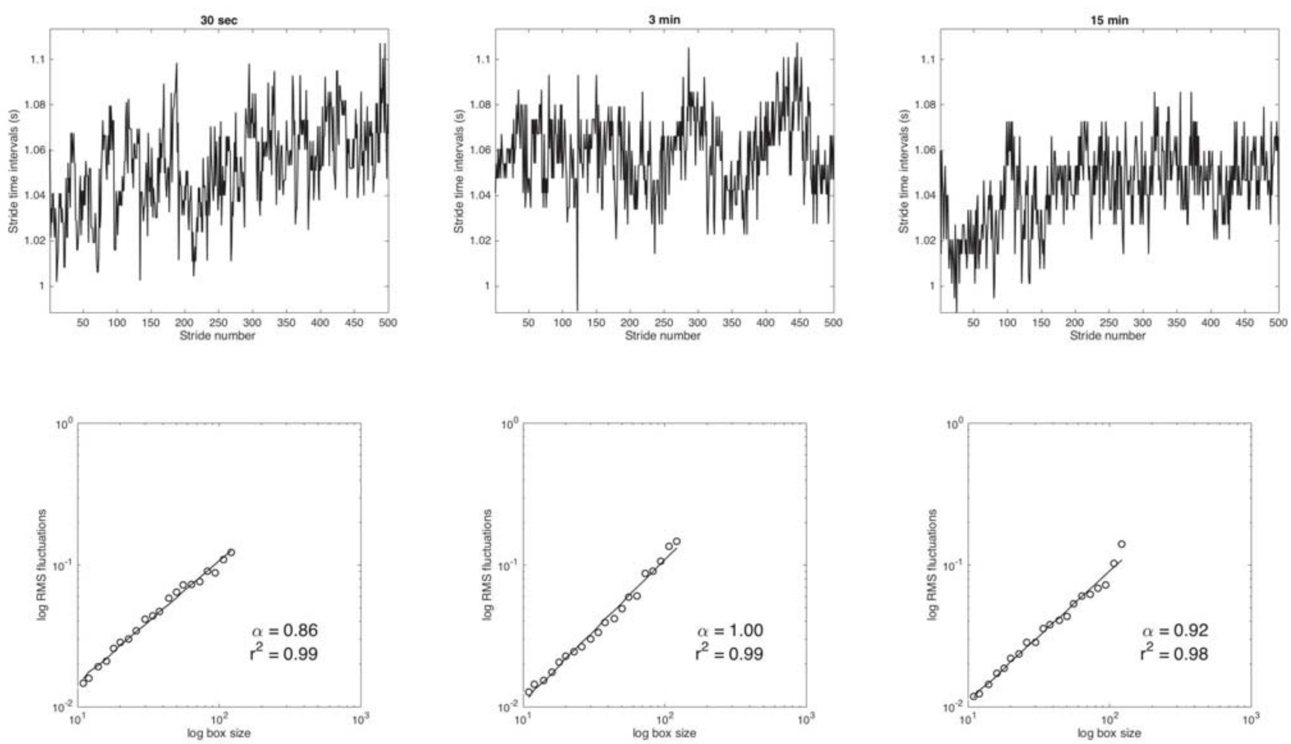

Figure 1: Stride-to-stride time intervals (upper panel) and corresponding DFA plot (lower panel) from subject #3 in the *'30 sec'* (left), *'3 min'* (middle) and *'15 min'* (right) conditions.

DETERMINING THE BEST PREDICTOR OF FUTURE FALLS IN PATIENTS WITH CHRONIC OBSTRUCTIVE PULMONARY DISEASE

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INTRODUCTION

Chronic obstructive pulmonary disease (COPD) is a chronic, progressive lower respiratory disorder characterized by airflow limitation with varying degrees of changing pathology in the lungs [1]. COPD is a leading cause of physician office visits, emergency department visits, and hospitalization in older adults. This pulmonary disorder is also linked with other comorbidities such as reduced quality of life, decreased physical activity, depression, and increased risk of cardiac events. Along with the destruction of the lungs and airways, COPD also affects the musculoskeletal system. Patients with COPD have muscle fatigue and weakness [2], along with gait defects and an increased risk of accidental falls [3]. Balance is affected in patients with COPD [3, 4].

The purpose of this pilot study was to examine several commonly utilized balance tests to see which tests would be a predictor of future falls in this population. We hypothesized that the functional balance tests would be a better predictor of future falls than subjective based measures.

METHODS

Seven patients with COPD (66.9±6.9 years) completed both functional and subjective based measures of balance at baseline. The functional tests included: Sensory Organization Test (SOT), Motor Control Test (MCT), Timed Up and Go (TUG), and the Fullerton Advanced Balance (FAB) scale. The SOT assesses the contribution of the somatosensory, visual, and vestibular systems to postural control over six varying sensory conditions (100=best). The MCT assessed the ability of the motor system to recover following an unexpected perturbation. The TUG requires subjects to stand up from a chair, walk ten feet, turn, and return (>14sec=high fall risk). The FAB tests both static and dynamic balance under varying sensory conditions with 10 performance-based activities (40=best). The subjective measures included: Activities Specific Balance Confidence scale (ABC) and the modified Falls Efficacy Scale (mFES) are subjective questionnaires ranking subject confidence in performing activities without losing balance or becoming unsteady (10 and 100%=fully confident, respectively).

After completing all balance testing, each subject was contacted via phone call once a week for ±6 months to inquire whether or not they have fallen or had felt unsteady. If the subject indicated that they fell or felt unsteady, details regarding the fall/unsteadiness were recorded, such as the circumstances surrounding the fall/unsteadiness, injuries resulting from the fall, and whether or not medical attention was sought.

RESULTS AND DISCUSSION

Data for each balance test and fall/unsteadiness were ranked. A Spearman rho rank-order correlational coefficient was performed on the ranked data between each balance test and their ranking of falls/unsteadiness with an added correction factor in case of a tie. Correlations values were considered strong if between ±1.0-0.6, moderate between ±0.590.3, and weak between ±0.29-0. One subject fell during the course of follow up. Two subjects reported unsteadiness on a frequent basis (>weekly) and two infrequently (1-4 times). A strong correlation between the TUG and ranking of unsteadiness was found.

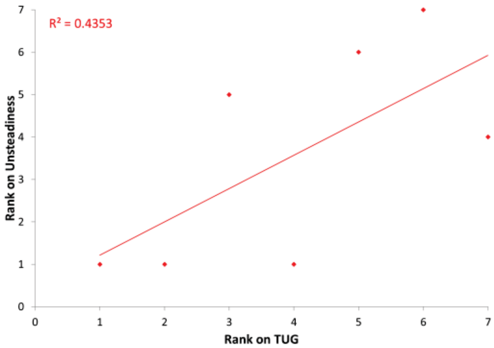

Figure 1. Subjects' ranking on the TUG score was strongly correlated with their ranking of feelings of unsteadiness (*rho* =.65).

Our pilot study suggests that patients with COPD who take a longer period of time to complete the TUG report an increased number of times of being unsteady. This means that subjects that ranked as having the poorest performance (taking the longest time to complete the task) on the TUG also reported the most falls and occurrences of unsteadiness. There was a moderate correlation between the rankings on the SOT and the rankings of falls/unsteadiness as well (rho=.35).

CONCLUSIONS

The TUG is a clinically relevant test and has been shown to discriminate fallers from non-fallers in a non-pathological, older adult population. The results to date of this pilot study suggests the TUG is the best predictor of future falls in patients with COP. We foresee forthcoming data to confirm that the TUG will be the best predictor of future falls in patients with COPD. TUG could easily and economically be implemented into clinical care, as a standard of balance assessment.

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Table 1: Spearman rho correlation values for each of and functional and subjective tests

	SOT	MCT	MFES	FAB	TUG	ABC
RHO	0.35	-0.11	0.25	-0.07	0.65	0.04

GAIT BIOMECHANICS IN PATIENTS WITH PERIPHERAL ARTERIAL DISEASE CAN BE PREDICTED BY QUALITY OF LIFE MEASURES USING STEPWISE LINEAR REGRESSION

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INTRODUCTION

For patients with peripheral arterial disease (PAD), the most limiting symptom is physical activity induced pain in the legs known as claudication. Clinically, little is done to assess function other than physicians interviewing them or walking with them to observe the patient's limitations firsthand. Quality of life questionnaires and treadmill and overground maximum walking distance tests are commonly used in research settings. Both types of assessments could potentially be implemented to understand functional limitations in a clinical setting. However, there is no consensus on the best functional walking test to use on these patients[1,2] and neither type of test has been directly compared with gait biomechanics, which is the gold standard for testing functional limitations[3]. Biomechanics testing cannot easily be performed on all patients in a clinical setting due to the cost, time, and equipment restraints. Therefore, this study sought to determine whether common research measures of quality of life and maximum walking distance could accurately predict gait biomechanics measures. We hypothesized that distances and quality of life parameters together would be predictors of gait variables in patients with PAD. If true, clinicians could confidently implement these methods into the clinical setting to better understand functional status in patients with PAD.

METHODS

One hundred and six patients diagnosed with PAD (age: 64.4 ± 6.7 years; ht: 174.3 ± 9.2 cm; mass: 86.9 ± 19.2 kg) were referred to the study by vascular surgeons. Consent was documented and the patients were given two different questionnaires: the Walking Impairment Questionnaire (WIQ)[4] and the Medical Outcomes Survey Short Form 36 (SF-36)[5]. The WIQ is a questionnaire specific to patients with claudication and it includes component scores for pain, distance, stairs, and speed. The SF-36 has been validated in multiple populations as a measure of quality of life and includes eight domain scores. The walking distance scores were determined by having subjects complete the Gardner treadmill test[6]. Subjects walked on a treadmill set at 0.86 m/s (2.0mph) at 0% grade. The grade of the treadmill was increased 2% every 2 minutes. The initial claudicating distance is the distanced walked prior to the first indication of pain and the absolute walking distance is the distance walked until the patient cannot walk any further and must stop the test. Additionally, the 6 minute walk test (6MWT) was performed, which is the distance patients can walk overground in 6 minutes[6].

For the gait biomechanics testing, 27 reflective markers were placed at anatomical positions[3]. Marker position data was recorded using a twelve camera motion capture system (Motion Analysis Corp., Santa Rosa, CA; 60 Hz). Ground reaction forces were captured by force plates in the overground runway (AMTI, Watertown, MA; 600 Hz). Subjects performed five trials through the overground runway on their claudicating leg during a pain free condition. The position data was tracked in Cortex software (Motion Analysis Corp., Santa Rosa, CA) and then processed for gait biomechanics variables in MATLAB (Mathworks Inc., Boston, MA) and Visual3D (C-Motion, Germantown, MD) custom software. Dependent gait biomechanics variables include peak joint angles, moments, and powers of the ankle, knee, and hip during the stance phase. Statistical analysis included a stepwise linear regression analysis using gait variables as the dependents and the quality of life and walking distances as predictors. For this analysis, the probability level for entry in to the model was set at 0.20 and the significance level of removal from the model set at 0.25. This analysis allowed multiple components of the quality of life measures to be used to predict the gait biomechanics variables. The primary gait outcome variables were ankle plantarflexor moment and ankle plantarflexor power due to previous work in our laboratory identifying the ankle as consistently deficient in patients with PAD. However, prediction models were developed for all ground reaction force, joint angle, joint torque, and joint power peak points from the stance phase.

RESULTS AND DISCUSSION

The models using quality of life questionnaires and walking distances to predict values were significant in 31 of 33 gait parameters tested. Very importantly, the 6MWT was a predictor in 21 of the 31 significant models. For all variables in which the six minute walk test was included in the model, as the distance walked increased, the value of the gait parameter was also improved, meaning it moved closer to healthy controls values in controls from our previous papers[8]. These findings suggest that the 6MWT distances are the best representative of gait parameters from all of the quality of life and walking distance parameters.

An important consideration when interpreting prediction models is the strength of the relationship, or the amount of variance in gait parameters that could be explained by the model. In this study, the significant relationships had r-squared values ranging from .108 to .383, which are not strong relationships. Thus, clinicians should be cautious in thinking that quality of life questionnaires and walking distances could provide the same knowledge as gait biomechanics parameters in patients with PAD. Rather, models of this strength can explain between approximately 10 and 40% of the variance in the specific gait variables and while the models may provide insight into functional status, they are insufficient to describe gait in these patients.

The purpose of this study was to determine whether or not clinicians could rely on quality of life questionnaires and walking distances to evaluate and understand the gait and function of patients with PAD. Previous studies have demonstrated that gait biomechanics are important outcome measures in assessing treatment efficacy in patients with PAD[7,8]. Furthermore, there is an argument in the literature regarding whether the treadmill or six minute walk test is optimal for assessing functional outcomes for clinical trials[1,2]. Based on the current study, the six minute walk test is the better of the two tests, but neither adequately represent the gold standard for lower extremity function, gait biomechanics. Importantly, this study emphasizes the need for more sophisticated, objective, and accurate methods that could provide stronger models with which to represent function in these patients.

CONCLUSIONS

Our results demonstrated that quality of life questionnaires and walking distances can explain between 10-40% of variance in gait biomechanics variables in patients with PAD. Future research should evaluate whether gait parameters assessed through portable devices like accelerometers and inertial sensors are more representative of gait biomechanics in these patients.

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EFFECTS OF UPHILL WALKING AND VISUAL UPHILL ENVIRONMENTS ON LOCOMOTOR-RESPIRATORY COUPLING AND ENERGY EXPENDITURE

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INTRODUCTION

To move any object against gravity requires energy, thus uphill walking requires more energy than level walking [1]. Uphill walking also affects walking mechanics when compared to walking on level ground [2-3]. However, it is possible that just the perception of uphill walking could require increased energy expenditure and alter respiratory rhythms, since our vision strongly influences how we walk. Previous research has shown that participants adjust walking speed to the perception of changing speed using virtual reality [4]. Additionally, altered respiration and locomotion due to uphill walking, may alter the coupling (or influence) between the two systems, which normally work together to minimize our energy requirements during exercise. The objectives of this research were to determine the effects of uphill walking and the perception of uphill walking through the use of virtual reality on 1) Locomotor-respiratory coupling and 2) Energy expenditure.

METHODS

Table 1: Demographical information.

N	Age (years)	Height (cm)	Weight (kg)
10 (6M/4F)	22.5±1.2	175.2±8.0	77.9±9.0

Ten healthy young participants (Table 1) walked on a treadmill for six, 5-minute conditions (Table 2) and also performed one standing, resting oxygen consumption test.

Table 2: List of inclines and virtual inclines for treadmill conditions.

	No VR	0%-VR	10%-VR	Oscillating VR
0%-TM	C01	C02	C04	C06
10%-TM		C03	C05	

Locomotion was measured using a 3D motion capture system (Vicon, Oxford, United Kingdom), respiration was measured using a custom-built resistive breathing sensor, and energy expenditure was measured using an indirect calorimeter (K4b2; COSMED, Rome, Italy). From these data, steady state energy expenditure was calculated and locomotor-respiratory coupling was calculated using two algorithms: discrete relative phase (DRP) and cross recurrence quantification analysis (cRQA).

DRP is used to explore the frequency and phasic relationship of the locomotor and respiratory systems. The frequency is calculated as the number of locomotor cycles that occur within a breathing cycle. This is done by taking a discrete event of the locomotor cycle (usually a heel strike) and counting how many occur within a breathing cycle (usually end of inhalation to the following end of inhalation). This ratio is expressed as strides:breaths. The phasic relationship is calculated by comparing a heelstrike to the corresponding heelstrike (i.e. 1st heelstrike to subsequent 1st heelstrike) in the following breath cycle to see if they occur at a similar percentage of the breathing cycle.

While DRP looks at the coupling between discrete events, cRQA looks at coupling in a more continuous manner. Information from cRQA indicates how often and how long the locomotor and respiratory systems are coupled. Additionally, each cycle of locomotion is compared to each cycle of respiration.

RESULTS AND DISCUSSION

Energy expenditure was only different between level and uphill treadmill conditions (Figure 1). It remained similar between virtual level and uphill conditions.

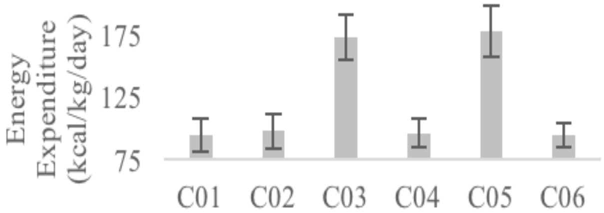

Figure 1: Energy expenditure calculated from indirect calorimeter.

No significant differences were seen between treadmill grade and virtual grade for any of the cRQA or DRP measures (Figures 2-4). The most common frequency ratio used during all conditions was 2:1 (strides:breaths). Although other ratios were also used, including 1.5:1, 2.5:1, 3:1, and 4:1. Additionally, some trials did not have a dominant frequency ratio and were considered to have no coupling.

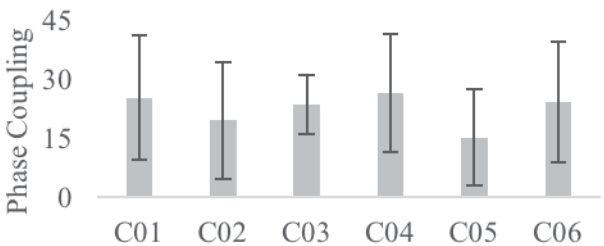

Figure 2: Measurement of phasic coupling strength between breathing and walking measured through DRP.

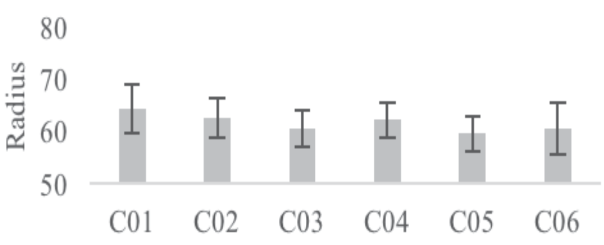

Figure 3: Radius to get 2.5% recurrence for cRQA.

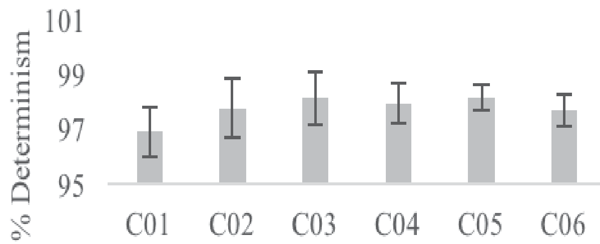

Figure 4: Percent determinism measured through cRQA.

CONCLUSIONS

A possible explanation for the similarities seen between all conditions is that uphill walking may be too easy of a task for healthy young adults. To elicit a change in their coupling patterns, a more difficult task, such as uphill running may be required to change the coupling between breathing and walking. Further research will include a healthy older group. Differences between the healthy young and healthy older groups may exist because of the increased reliance on vision as we age. Additionally, differences between the conditions may exist for the health older adults for this same reason and the virtual uphill and virtual level conditions will show differences.

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ACKNOWLEDGEMENTS

We would like to thank the University of Nebraska-Omaha's Office of Research and Creative Activity and NASA Nebraska Space Grant for providing funding for this research.

EFFECT OF 3D PRINTED PROSTHETIC DEVICE ON MUSCULAR ECHO INTENSITY AND MORPHOLOGY IN PEDIATRIC AMPUTEES

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INTRODUCTION

There are increasing numbers of children with traumatic and congenital hand amputations or reductions. Children's prosthetic needs are complex due to their small size, constant growth, and psychosocial development. Families' financial resources play a crucial role in the prescription of prosthetics for their children, especially when private insurance and public funding are insufficient. Due to the complexity and high cost of these prosthetic hands, they are not accessible to children from low income, uninsured families, or to children from developing countries.

SIGNIFICANCE OF PROBLEM

Creighton University's 3D Research & Innovation Laboratory has taken advancements in computer-aided design (CAD) programs and additive manufacturing (3D printing) to develop and print a prosthetic device, the Cyborg Beast. This low-cost, wrist-driven, 3D printed device was created to address the previously discussed issues. Since its creation, about two-dozen children have been using the device and many more are expected to use it in the future. Therefore, due to the increasing number of children utilizing our device, we wish to analyze the effect of the Cyborg Beast on its user's forearms over time.

HYPOTHESIS, PROBLEM, OR QUESTION

It has been previously suggested that muscular echointensity (EI), muscle fiber pennation angle, and muscle compartment thickness are indicators of muscle quality. Our case study looked to develop a systematic approach in order to analyze these variables as a means to quantify the effects of using the Cyborg Beast over time.

EXPERIMENTAL DESIGN

Participant is a 12 year-old male transradial amputee custom fitted with the Cyborg Beast prosthetic device. The participant's affected and non-affected (control) forearms were evaluated with ultrasound imaging three times over the course of 18 months.

Sagittal and coronal ultrasound images of the affected and unaffected (control) forearms were obtained. Sagittal ultrasound images were analyzed with an image-editing program (ImageJ, version 1.46, NIH) to obtain the mean of EI of the muscles of interest. Coronal ultrasound images were analyzed with the program Tracker (Tracker, version 4.91, OSP) to determine muscle fiber pennation angle and muscle compartment thickness. Data was gathered during three visits over the course of 18 months.

RESULTS/DATA

After using the Cyborg Beast prosthetic device for 18 months, our subject showed increases in EI in both affected and non-affected extensor and flexor compartments. His muscle thickness increased each visit in both limbs and all compartments, except his non-affected extensor compartment decreased each visit. Lastly, our subject's muscle fiber pennation angle showed an overall increase at each visit, except for his affected extensor digitorum, which showed an overall decline in angle.

CONCLUSION

The main finding in this case study was that the ultrasound analysis showed unexpected increases in EI and pennation angle, but predictable increases in muscle compartment thickness. Previous studies establishing these 3 variables as determinants of muscle quality were performed in adult populations. However, a prepubescent child is likely to experience both longitudinal and circumferential muscular growth, producing the increases in EI and pennation angle seen here. By establishing these variables in children and tracking the changes over time, we can assess the Cyborg Beast's effect on its users, ultimately helping them gain strength and improve their activities of daily living. Future studies will investigate a greater number of Cyborg Beast users along with additional variables such as time spent wearing the device, tests of muscular strength, and EMG data.

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ACKNOWLEDGEMENTS

Thanks to the students and faculty from the 3D Research & Innovation Laboratory at Creighton University (http://www.cyborgbeast.org/) who helped with data collection.

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COPD: A POTENTIAL BIOLOGICAL AGING CATALYST FOR BALANCE DEFICIENCIES

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INTRODUCTION

Persons affected by chronic obstructive pulmonary disease (COPD) suffer from a litany of respiratory ailments including, shortness of breath, sputum production, and coughs due to overall degeneration of lung tissue and capacity[1]. Over 329 million worldwide are affected by COPD[1]. It is currently the third leading cause of death in the United States and fourth worldwide[1].

COPD is not just a disease of the lungs. Patients with COPD report muscle fatigue[2], decreased levels of physical activity[3], and balance problems are well documented in this population[4,5]. Patients with COPD fall more often and are at increased risk of falls than their healthy counterparts[4]. Patients with COPD also demonstrate balance deficits in the medio-lateral direction during standing balance[5]. The majority of these studies have investigated balance and falls in patients with COPD that are elderly (>70 years)[4,5]. However, the pathophysiology of COPD can begin at a much younger age (e.g., 40 years). It is feasible that the systemic effects of the disease affect the functional outcomes of patients at a much younger age, independent of the aging process. Our purpose was to provide delineation between the presence of disease and the aging process by investigating balance in both young and older patients with COPD. We hypothesized that presence of disease would lead to balance deficits in younger COPD patients.

METHODS

Seven patients with COPD (4 ≥65yrs: 74.8±6.4yrs; 3 ≤65yrs: 56.3±6.8yrs) and 19 controls (5 ≥65yrs: 70.8±6.4yrs; 14 ≤65yrs: 55.7±6.0yrs) performed a series of balance measures: sensory organization test (SOT), motor control test (MCT), modified falls efficacy scale (mFES), Fullerton advanced balance scale (FAB), timed up and go (TUG), and activities-specific balance confidence (ABC) scale. The SOT assesses the three sensory systems that control balance (vision, somatosensory, and vestibular) and the resulting equilibrium score is ranked on a 0-100% scale, where 0%=reaching the point of falling or has fallen. The MCT examines the body's automatic response of correction of posture to a moving surface through a latency score; a larger score indicates that it takes longer for the nervous system to respond to a perturbation. The mFES is a subject questionnaire that pertains to their fear of falling while completing daily tasks and scores less than eight are indicative of a fear of falling. The FAB is a series of balance tests to assess the subject's ability to use their somatosensory cues to maintain upright balance in varying situations that are scored on a range from zero to four; scoring less than 25/40 is considered to be at risk for falling. The TUG measures mobility and fall risks for time by having the individual rise from a chair walk out and back three meters, then sit back down; >10 seconds are generally considered abnormal mobility. The ABC

Scale is a confidence-based questionnaire pertaining to confidence in completing normal daily activities without falling; a mean of less than 67% indicates a risk of falling. Repeated measures ANOVA (age group x disease presence) was performed on each balance test with $\alpha \leq 0.05$ to determine significance.

RESULTS

ANOVA results demonstrated a main effect for SOT ($p=0.011$), mFES ($p=0.006$), FAB ($p<0.001$), ABC ($p=0.036$), and no effect for the TUG ($p=0.054$) or the MCT ($p=0.061$) (Table 1). A main effect for the MCT and TUG is expected with the collection of more data. Contrary to our hypothesis, young COPD were not significantly different than the control groups. However, they performed worse on the SOT, MCT, TUG, and ABC than both control groups. Scores for balance tests progressively declined in the older COPD group and demonstrated a significant deficit from young controls.

DISCUSSION

Failure to observe a difference in younger patients with COPD may be related to the small sample size. However, the study is ongoing and we theorize a larger sample size will garner results more in line with the hypothesis. Significance lies in the evidence of balance deficits in younger adults, an earlier intervention by way of balance training could decrease incidences of falls in older COPD populations. Further investigation with larger sample sizes is recommended to better quantify differences between COPD and the aging process.

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ACKNOWLEDGMENTS

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Table 1: Mean(SD) for all balance measures for each group tested.

	SOT (%)	MCT (sec)	mFES	FAB	TUG (sec)	ABC
Young Control	75.6(7.0)	132.1(6.3)	10.0(0.1)	38.2(1.9)	5.8(1.4)	95.3(6.9)
Young COPD	69.0(10.4)	136.3(120.6)	9.5(0.7)	35.0(1.0)	7.7(1.7)	84.8(14.4)
Older Control	74.2(6.5)	126.2(3.9)	10.0(.03)	38.8(1.3)	5.7(1.6)	97.3(2.8)
Older COPD	57.3(15.1)	160.5(69.9)	7.9(2.5)	26.3(8.8)	8.6(3.5)	69.8(36.7)

STRUCTURED AUDITORY STIMULATION AFFECTS HUMAN MOVEMENT VARIABILITY AND ASSOCIATED CORTICAL INVOLVEMENT

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INTRODUCTION

Previous research has shown that variability present in simple human movements is not random, but deterministic, with a characteristic fractal structure [1]. In rhythmic tapping and human gait, this fractal organization can be driven by synchronizing movements with a fractally structured auditory stimulus [2, 3]. Similar fractal organization has been detected in fMRI BOLD [4] and fNIRS [5] signals in resting states and during simple movements. This study investigates the relationship between the fractal organization of tapping movements driven by structured auditory stimuli, and the fractal organization in the central nervous system as revealed in cerebral hemodynamics measured by fNIRS.

METHODS

Experiment 1: Sixteen participants performed 5 continuous repetitions of 30 seconds of right-hand tapping followed by 30 seconds of rest. Mean levels of oxygenated (HbO) and deoxygenated (Hb) hemoglobin during the tapping periods were compared to those of the previous rest periods over each region of interest. Regions of interest included the supplementary motor area (SMA), left and right primary motor cortex (PMC), and left, right, and medial sensory motor cortex (SMC) [6].

Experiment 2: Sixteen participants performed a series of 15 minute trials, consisting of sensorimotor synchronization to an auditory stimulus. Four designed auditory stimuli were presented in random order. The stimuli consisted of versions of "Für Elise" that were played with either no variability in a metronome condition, or variability added to the inter-beat intervals in the white-, pink-, and brown-noise conditions. Participants were instructed to tap in synchrony to the notes using their right hand, and the taps were recorded using a pressure sensor. Mean, standard deviation, and detrended fluctuation analysis scaling exponent (DFA α) of inter-beat interval (IBI) and inter-tap interval (ITI) were calculated for each stimulus. In addition, HbO and Hb were measure for each trial. The mean, standard deviation, and DFA α of HbO and Hb were compared over stimulus and regions of interest. Regions of interest were the same as in Experiment 1.

RESULTS AND DISCUSSION

A comparison of the tapping and rest conditions in Experiment 1 shows a significant increase in HbO and corresponding decrease in Hb during tapping in regions of interest located over the left side of the primary motor cortex and sensory motor cortex (Figure 1). When tapping and rest conditions were compared for regions of interest on the right side, no significant differences were found in HbO and Hb.

In Experiment 2, the average cross-correlational functions between IBI and ITI series in the four auditory conditions are shown in Figure 2. Long-range correlations are observed for the pink- and brown-noise conditions. The mean and standard deviation of HbO and Hb were not significantly different across stimulus or regions of interest, but DFA α of HbO shows a significant main effect of stimulus on regions of interest on the left side (Figure 3).

As shown in previous work [2, 3], coordinated motor output was entrained to the subtle variability structure of the environmental stimuli. Long-range correlated structure in the auditory stimuli resulted in similarly structured tapping variability. The variability structure of motor behavior was also reflected in cerebral hemodynamics. These results suggest that the dynamics of neural activation in the sensory motor cortex reflect the subtle task-specific long-range structured variability of motor behavior.

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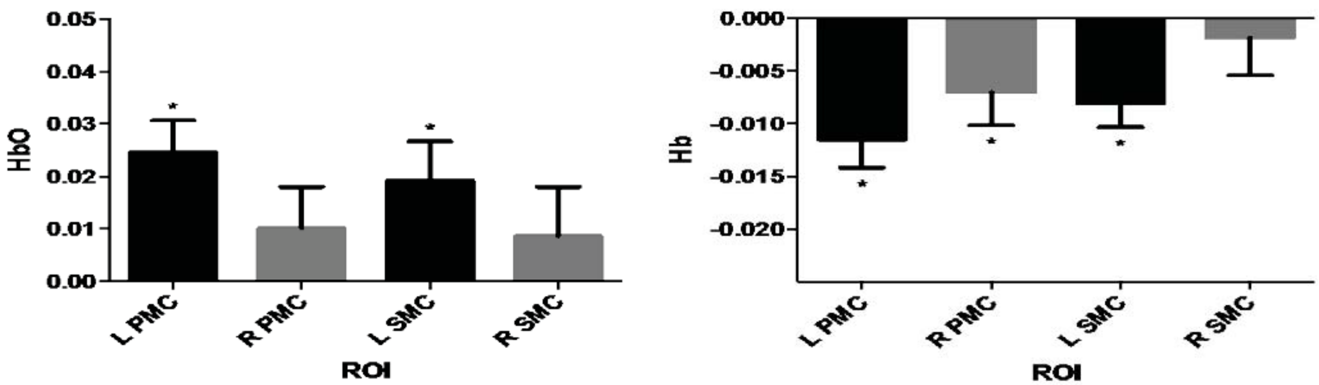

Figure 1: Increase in HbO (left panel) and decrease in Hb (right panel) during tapping in left and right primary motor cortex and sensory motor cortex.

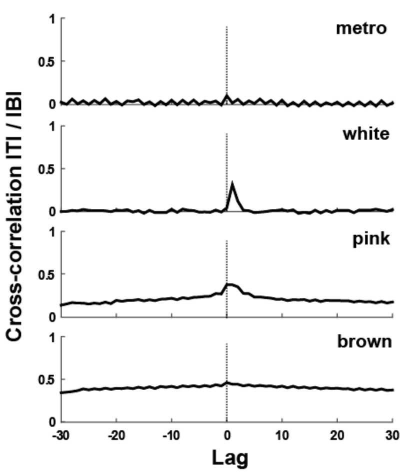

Figure 2: Average cross-correlational functions between IBI and ITI series for four auditory conditions.

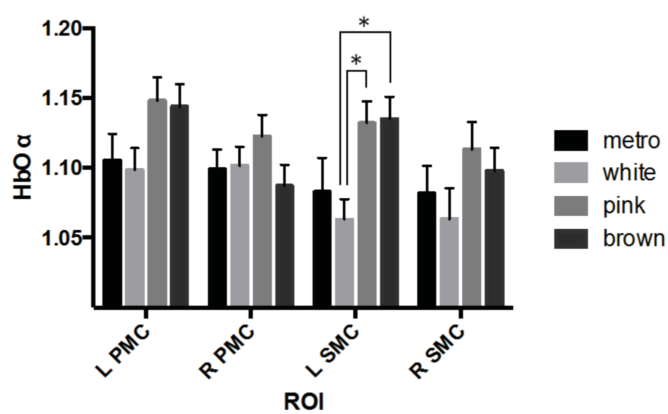

Figure 3: DFA α of HbO in regions of interest for four auditory conditions.

CROSS-WAVELET ANALYSIS OF FORCE PLATE OUTPUTS SUPPORTS A COORDINATION DYNAMICS OF QUIET STANDING POSTURE.

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INTRODUCTION

From the theoretical perspective of coordination dynamics behavior is assumed to be constrained by principles of self-organization (Kelso, 1995). The major predictions of coordination dynamics are drawn from the HKB model. Named for its authors (Haken, Kelso, & Bunz, 1985) the HKB model models the dynamics of relative phase (ϕ) for a system of two coupled non-linear oscillators. These dynamics are captured in the following motion equation:

$$\dot{\phi} = \Delta\omega - a\sin(\phi) - 2b\sin(2\phi).$$

$\Delta\omega$ models magnitude of asymmetry between coupled oscillators. This asymmetry can be either mechanical (e.g. coordinated pendula with differing natural frequencies) or informational (e.g. attention directed preferentially to one coordinated element) (Treffner & Turvey, 1995). The ratio b/a models the coupling strength between coordinated elements. The HKB model makes the following predictions:

HKB Prediction 1: Stable modes of coordination exist, typically as stable fixed points at $\phi = 0^\circ$ and $\phi = 180^\circ$.
HKB Prediction 2: When asymmetry (modelled as $|\Delta\omega|>0$) is present, a shift in relative phase away from either $\phi = 0^\circ$ and $\phi = 180^\circ$ will be observed (e.g. from $\phi = 0^\circ$ to $\phi = 20^\circ$).
HKB Prediction 3: For weakly coupled and/or systems with asymmetries stable fixed point attractors are lost and are replaced by ghost attractors, with the system now found to exhibit only a tendency to preferentially visit particular relative phase values close to where fixed point attractors had once been. A system with these qualities is referred to as metastable.

Recent research suggests that the HKB model can be applied to postural control. Coherence analysis of limb kinematics during quiet stance has revealed the presence of stable coordination between trunk and leg segments (Zhang, Kiemel, & Jeka, 2007). Moreover, analysis of coordination between the center of pressure (COP) measures across the two feet reveal epochs of phase synchronization consistent with metastability (Wang & Newell, 2012).

Here we test the predictions of the HKB model. We hypothesized that cross wavelet analysis of the COP trajectories and ground reaction forces (GRF) under the left and right feet would reveal a metastable coordination dynamics. We predicted epochs of stable coordination between studied variables, with evident preferences for $\phi = 0^\circ$ and $\phi = 180^\circ$. We also predicted that asymmetries resulting from 1) asymmetric stance (Figure 1) and 2) from "right footed" participants would result in a shift in relative phase away from $\phi = 0^\circ$.

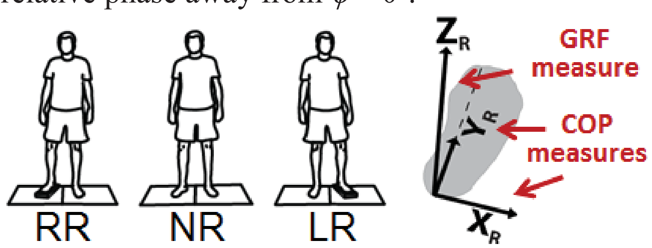

Figure 1. Manipulation of stance symmetry using a solid block to raise either the left foot (LR), the right foot (LR), or neither (NR). Right panel shows measures taken for each foot (right foot shown).

METHODS

Thirteen young healthy adults took part in the study. All participants were right footed as determined by a simple function test of preference for kicking a soccer ball.

Participants performed 35 s duration trials of standing quietly. Stance symmetry was manipulated across trials (Figure 1, left panel). Tracings of the outline of comfortable stance foot placement obtained at yej start of the experiment were used to control foot position across trials.

Time series of ground reaction force (GRF) and the center of pressure (COP) under the left and right feet were obtained at a sampling rate of 100 Hz using two side-by-side force plates. Time series of X, Y and Z for the left and right side were standardized, and coordination between the resulting six standardized time series was investigated.

Coordination was studied between pairings of these six outputs (e.g. X_RY_L) employing cross-wavelet analysis (CWA). The primary measures derived from the CWA employed in our analysis were the percentage of each trial exhibiting above chance coherence (PTC) and wavelet relative phase (ϕ). Measures were calculated for all output pairs at five frequency bands.

RESULTS AND DISCUSSION

Analysis of the wavelet relative phase (ϕ) values taken from determined regions of frequency coordination, revealed a tendency for the pairings of the X, Y and Z outputs studied to each be coordinated in particular phase modes, specifically $\phi = 0^\circ$ and $\phi = 180^\circ$. This can be clearly seen in the relative phase histogram in figure 2 that includes all fifteen outputs pairs and all five frequency bands. This figure reveals that on average stable coordination across outputs was only evident for a fraction of each trial. These results are consistent with metastable coordination.

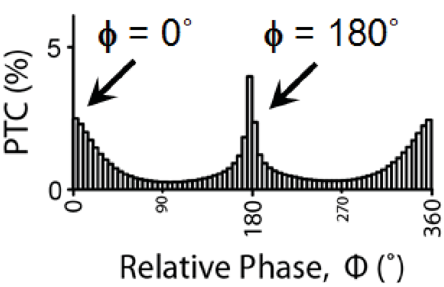

Figure 2. Relative phase histogram.

An analysis of mean ϕ for Y_LY_R was used to investigate hypothesized phase leads resulting from asymmetries. A main effect of stance symmetry, $F(2,12) = 53.53$, $p < .001$, was observed. Moreover, a phase lead of the preferred (right) limb was observed in the NR condition $t(12) = 2.29$, $p < .05$.

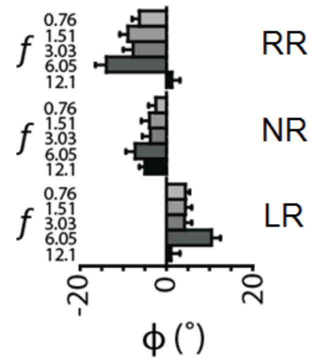

Figure 3. Mean ϕ for Y_LY_R for regions of above chance coordination classified as in-phase.

CONCLUSIONS

Cross wavelet analysis reveals epochs of coordination across degrees of freedom during quiet standing. The relative phase of coordination within the determined epochs of above chance coherence, and the change in phase resulting from asymmetry, are both consistent with predictions from coordination dynamics regarding metastability and detuning respectively.

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Title: The variability of minimum toe clearance decreases in both healthy young and healthy older adults during dual-task treadmill walking

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Introduction:

Daily activities require the management of motor-cognitive tasks. To successfully perform such tasks without losing balance during walking, increased minimum toe clearance (MTC) and increased gait variability have been reported in older adults during over ground walking (Hamacher et al., 2014). In the current study, we investigate variability of MTC and stride time during dual-task treadmill walking. We hypothesized that the MTC variability, but not stride time variability would change during dual-task treadmill walking.

Methods:

Ten healthy young (19-35 years) and 10 healthy older adults (over 65 years) walked on a treadmill for three minutes at their preferred pace while kinematics were recorded. Subjects walked at baseline and during each of the three conditions of the dichotic listening (DL) test (non-forced, forced right, and forced left). Standard deviation was calculated for MTC and stride time in each condition. A mixed ANOVA was used to determine differences between conditions and groups.

Results and Discussion:

A significant condition effect ($p = 0.03$) was found for MTC variability. MTC variability decreased during the dual-task conditions. There was no significant group effect or interaction for MTC variability. There was a significant group effect for stride time variability, with the young having lower stride time variability than the older group. There was no significant effect or interaction for condition. Results indicated that MTC variability is controlled more closely while subjects perform a dual-task, perhaps to avoid a trip and fall. Future studies should investigate MTC variability during dual-task walking in individuals with previous falls.

Hamacher, D., Hamacher, D., & Schega, L. (2014). Towards the importance of minimum toe clearance in level ground walking in a healthy elderly population. *Gait & posture*, *40*(4), 727729.

THE EFFECT OF FATIGUE ON PELVIS AND TRUNK MOVEMENT VARIABILITY IN THE SOFTBALL WINDMILL PITCH

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INTRODUCTION

Softball is a sport that has gained popularity in the past decade. Softball pitching is a unique movement with its windmill-style pitches. Based upon the principles of the leading joint hypothesis, control of the proximal joints largely contribute to the overall performance of a movement [1]. The kinematics of the pelvis and torso may provide key information on the performance of the softball pitch [2].

Unlike their baseball counterparts, softball rosters do not carry many pitchers. As a result, softball pitchers must pitch much more frequently. Resulting fatigue may affect the ability of the athlete to consistently coordinate her movement to optimize performance. It is possible that a change in the variations of an athlete's movement may hinder her performance.

Variability is inherent in all human movement [3]. From a dynamical systems perspective, variability can be seen as a key component of movement that allows for adaptation to system perturbations [3]. Investigation into the structure of variability can uncover some of the motor control strategies that cannot be detected by traditional measures of the amount of variability [3].

The purpose of this study is to investigate the variability of the pelvis/torso movement sequence during the windmill pitch before and after fatigue.

METHODS

Four female division-1 collegiate softball pitchers (age: 20.8 ± 1.0 years; height: 168.5 ± 5.1 cm; body mass: 92.2 ± 21.5 kg) participated in this study. Fast-ball pitches were analyzed under two conditions: pre-fatigue and post-fatigue. Participants performed 20 pitches in the pre- condition and 15 pitches in the post- condition. Full-body kinematic data were recorded at 250 Hz (Qualisys, Göteborg, Sweden).

The fatigue protocol was designed to simulate the fatigue that a pitcher may experience during a game. Upon completion of the pre- trials, the participant pitched 20 fast-balls as quick as possible, rested for 30 seconds, then pitched 20 more fast-balls. Immediately following the second set of 20 pitches, pitches were recorded for the post- condition.

Transverse plane segment angles for the pelvis and torso were calculated using Visual 3D software (C-Motion, Germantown, Maryland). All pitches were analyzed from push-off, which was defined as the moment of maximum anterior propulsive force, to release, which was defined as the frame where the ball is no longer in visual contact with the hand.

Cross-correlations were calculated to determine the degree of similarity between the pelvis and torso angular positions [4]. A dependent T-test was then used to identify any significant differences between pre- and post-fatigue conditions with significance set at $p < 0.05$. Earned run average (ERA) was measured throughout the season to determine performance. A spearman's rho correlation was used determine the relationship between the cross-correlation of the pelvis/torso and ERA performance.

RESULTS AND DISCUSSION

Cross-correlation, performance, and demographic data are presented in Table 1. All cross-correlations are presented with a time lag of 0. Results show no difference in measures between pre- and post- conditions (p = 0.14). Large differences in motion between the pelvis and torso in the transverse plane are difficult to accomplish without exaggerated, uncoordinated movements. Thus, it is not surprising that no differences are seen.

Spearman's rho results show a strong relationship between cross-correlation values and ERA (ρ = 0.80). There is a strong degree of similarity between the pelvis and torso for participants 1 and 4 (r = 0.91 and 0.95 respectively in pre- condition). However, participants 2 and 3 show only a moderate degree of similarity (r = 0.78 and 0.73 respectively in pre- condition). It is worth noting that participants 2 and 3 also have the lowest ERA on the team (3.26 and 3.32 respectively), suggesting that perhaps more similar movement of the pelvis and torso allows for a more efficient pitch.

It has been suggested that movement patterns may be based on morphological factors, biomechanical factors, environmental factors, and task constraints [4]. In the current study, the task and environment are all identical. However, biomechanical factors may be a factor with a subject range of different body types. Subjects carrying more mass around the pelvis and torso region could be a factor in influencing the movement patterns of these segments.

While it is difficult to make a decisive statement with a small sample population, this data shows exciting promise about the analysis of movement variability as a performance indicator in softball pitchers.

Table 1: Mean and standard deviation cross correlations. PRE = pre-fatigue; POST = post-fatigue; IP = Innings Pitched; ERA = Earned Run Average. No significant differences were found.

Participant	PRE	POST	IP	ERA
1	0.91 ± 0.01	0.90 ± 0.01	82	4.20
2	0.78 ± 0.05	0.77 ± 0.04	139	3.26
3	0.73 ± 0.03	0.73 ± 0.04	6.1	3.32
4	0.95 ± 0.01	0.92 ± 0.01	98	4.26
AVG	0.84 ± 0.10	0.83 ± 0.10		

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Thank you to the Nebraska softball coaching staff for without whom, this project would not be possible.

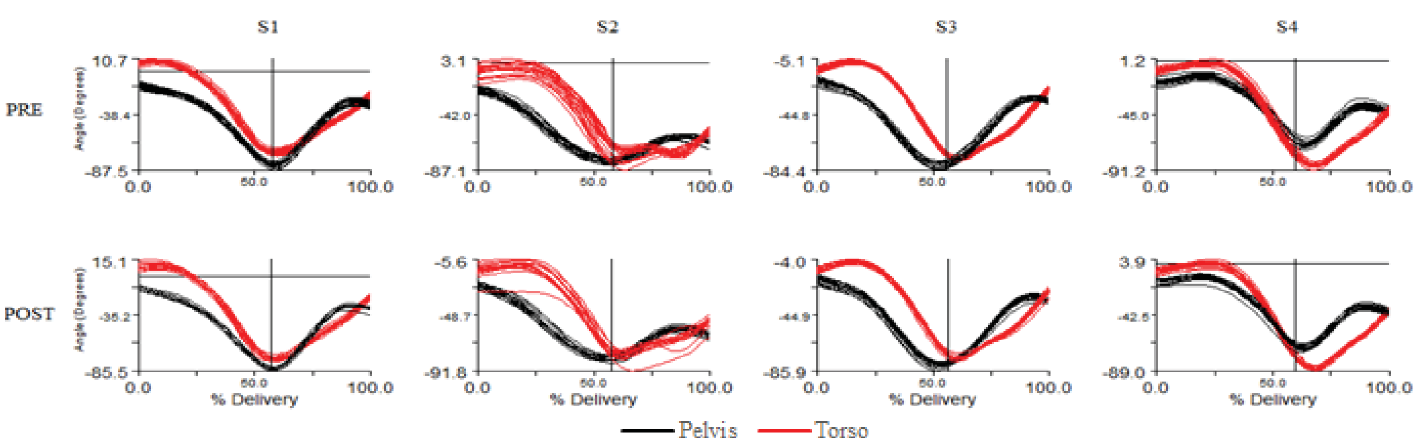

Figure 1: Time series of the pelvis and torso angle plotted with respect to time. Plots depict the phase of the pitch from maximum push-off to release. The vertical line depicts the moment at which the arm is at the highest position.

Dual Tasking in a Virtual Reality Environment:Does Auditory Selective Attention Impact Gait?

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During dual-task walking, slower step time andmore double support time may be an attempt by individuals to feel more stable. This project investigated dual task costs of a auditory selective attention task. Eleven healthy older adults (74$\pm$6 years) completedfour conditions (walking-only trial and non-forced, forced-right and forced left conditions of the dichotic listening test)in both virtual reality (VR) and non-virtual reality (NVR) sessions on a self-paced treadmill.Differences in step time and double support time between conditions and sessions were assessed using a two-way repeated ANOVA ($p<0.05$). There was a significant main effect of condition, with double support time significantly increased in the NVR versus the VR condition. There was also a significant interaction for double support time, with the forced-left condition being significantly different from the walking only, non-forced, and forced-right conditions. The forced-left is significantly increased compared with the other three conditions. Increased double support time has been commonly shown in aged groups compared to healthy young and in pathological groups versus healthy groups in the literature. Thus, our results are consistent with the VR improving the double support time in older individuals. In contrast, the most difficult condition of the selective attention task, the forced left condition, made the double support time more abnormal. These preliminary results indicate that cognitive tasks requiring greater auditory selective attention gait in older individuals and that VR may help to decrease the effect of a cognitive dual task.

THE ROLE OF VESTIBULAR PERCEPTION IN LEARNING A NOVEL LOCOMOTOR TASK

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INTRODUCTION

Healthy locomotion is characterized by an optimal level of movement variability [1]. The degree of variability healthy individuals display is the result of many years of practice. The learned walking pattern needs to be stable enough to be performed relatively effortlessly, yet variable enough to allow for adaptation to changes in the environment. When significant changes happen in the environment or in the body, we need to learn a new walking pattern, more appropriate under the new conditions. For example after a stroke, affected individuals need to learn to walk optimally even when one side of the body no longer functions as well as before. The learning of new movements and actions can be characterized by initial large errors, followed by a gradual minimization of movement errors until a stable level is reached. The errors we make during learning are beneficial because they explicitly show us what we are doing wrong [3]. This suggests we can improve a person's ability to learn a new locomotor task by stimulating the making of movement errors in a controlled environment.

METHODS

There were a total of 18 subjects. All subjects walked on a split-belt treadmill. There were a total of 7 trials; a baseline trial (0.5-1.0 m/s, slowly increasing the speed of the trial), a slow walking trial (0.5 m/s), a fast walking trial (1.0 m/s), a first split belt trial (right leg @ 0.5 m/s and left leg @ 1.0 m/s), a second split belt trial (right leg @ 0.5 m/s and left leg @ 1.0 m/s), a catch trial (0
5 m/s), and a third split-belt trial (right leg @ 0.5 m/s and left leg @ 1.0 m/s). 9 subjects (21.3 ± 0.9 yrs) did not receive any vestibular stimulation, while the other 9 subjects (22.3 ± 3.6 yrs) received vestibular stimulation, but all **s**ubjects had the vibrotactile device attached to the mastoid process on either side while walking. Vestibular stimulation was received for 9 of the subjects while adapting to the split-belt trials.

The subject's walking data was recorded by tracking the position of reflective markers attached to the ASIS, PSIS, ankle, toe, and heel. The baseline trial, first split-belt trial, and third split-belt trial were compared. The data was normalized and step length symmetry, as well as the coefficient of variation of step length and double support time, was calculated for each group. Group average values were compared.

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RESULTS AND DISCUSSION

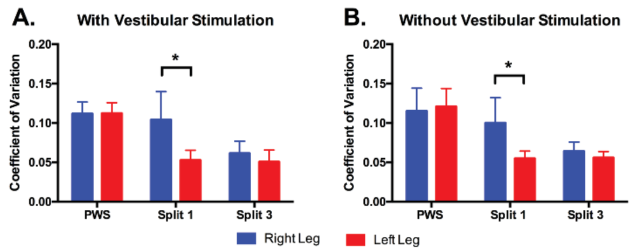

Figure 1: Step length coefficient of variation shows to statistically significant difference between the left and right legs

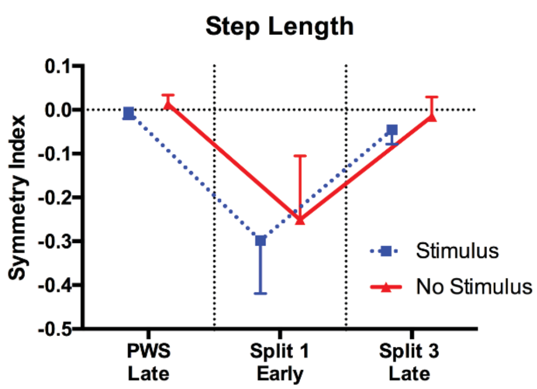

Figure 2: The coefficient of variation in step length symmetry showed no statistically significant differences between subject's that received stimulation and those that did not

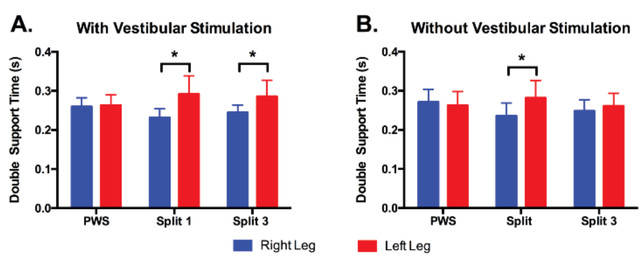

Figure 3. There is a higher double support time in the third split-belt trial in subject's that received vestibular stimulation than in subject's that did not

CONCLUSIONS

Individuals use input from vision, somatosensory, and vestibular systems to correct errors during locomotion. When the vestibular system is disrupted, the other two systems are more heavily weighted, helping to correct errors in locomotion without the vestibular system.

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COMPARISON OF GAIT VARIABILITY AMONG PATIENTS WITH PERIPHERAL ARTERY DISEASE WITH AND WITHOUT RELATED PATHOLOGIES

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INTRODUCTION

Peripheral artery disease (PAD) is a cardiovascular disease that results from the blockage of one or more arteries in the lower extremity [1]. These atherosclerotic blockages lead to claudication, which is muscle pain in the legs, caused by walking and relieved with rest. Recent work has shown that studying walking patterns of patients with PAD can provide important information about patient function [2]. Specifically, differences in gait variability are a promising way for clinicians to evaluate the severity of patients′ walking problems and whether treatments are effective in improving function.

It is common for those with PAD to also have related pathologies, including diabetes or foot ulcers [3, 4]. Non-healing foot ulcers result from limited blood flow to the feet, while diabetes is common because the risk factors are similar between the two pathologies. It is currently unknown how these common pathologies influence function and treatment response. This study used gait variability to determine the impact of non-healing foot ulcers and diabetes, on function. We hypothesize that patients with PAD and diabetes (PAD-D) will have different gait variability than those with PAD only (PAD-O). We also hypothesize gait variability will be different in patients with PAD and a foot ulcer (PAD-U) versus PAD-O. If proven to be correct, physicians will better understand how these pathologies affect function, allowing them to make better informed treatment prescriptions for these groups of patients.

METHODS

Subjects were recruited from local vascular surgery clinics and placed into their respective PAD-O, PAD-D, or PAD-U groups (Table 1). Subjects reported to the Gait Analysis Laboratory in the Biomechanics Research Building where they provided written, informed consent to participate in the study. Reflective markers were placed on the legs according to a modified Helen Hayes alignment that included a minimum of three markers per segment [5, 6]. Marker position data was collected using a 12-camera Motion Analysis system (Motion Analysis Corp., Santa Rosa, CA). The data was acquired with Cortex software at 60 Hz (Motion Analysis corp., Santa Rosa, CA) and processed using custom software in MATLAB (Mathworks Inc., Boston, MA) and Visual3D (C-Motion, Germantown, MD). This software was used to calculate the continuous flexion and extension angles of the ankle, knee, and hip and calculate the variability measures from each of those time series. Specific outcomes include amount of variability (standard deviation and coefficient of variation of the range of motion time series), and structure or pattern of variability (sample entropy and Lyapunov exponent) for the ankle, knee, and hip time series. The six-minute walk distance, and initial and absolute claudication distances (Gardner graded treadmill protocol) were also assessed. A one-way ANOVA was used to detect differences between groups ($p=0.05$).

RESULTS AND DISCUSSION

After comparing gait variability between patients with PAD and patients with PAD and related pathologies, we have found that there were five significant main effects. Those included knee and ankle coefficient of variation (Figure 1; $p<0.046$, $p<0.008$), ankle standard deviation ($p<0.022$), six-minute walk distance ($p<0.014$), and absolute claudication distance (p<0.022). The Tukey post-hoc test revealed that there were significant differences in the six-minute walk distance, initial claudication distance, and absolute claudication distance between groups PAD-O and PAD-D (p<0.017, p<0.043, p<0.017), and PAD-O and PAD-U (p<0.021, p<0.037, p<0.023).

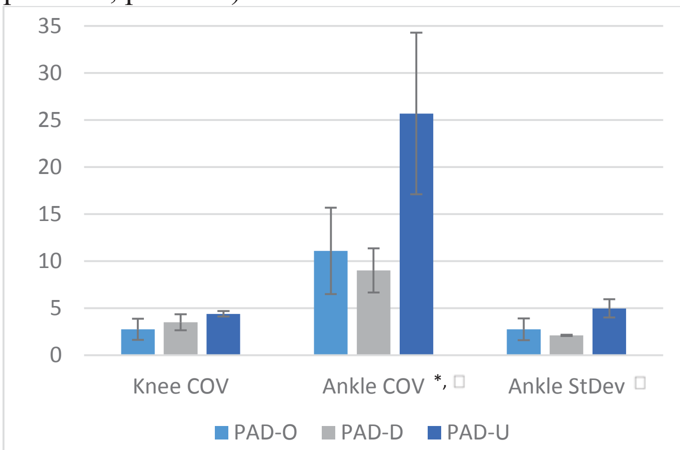

Figure 1: The significant interactions for knee and ankle coefficient of variation, and ankle standard deviation. *Significance between PAD-O and PAD-D. ♀Significance between PAD-O and PAD-U. ▣Significance between PAD-D and PAD-U.

CONCLUSIONS

Patients with PAD and patients with PAD and co-morbidities had differences in ankle and knee coefficient of variation, ankle standard deviation, walking distance, and claudication distance, thus supporting both of the proposed hypotheses. Looking at these results, it is clear that the ankle is affected the most by PAD, followed by the knee. This is not surprising considering the ankle is the most inferior joint to the leg blockages and muscles around that joint are receiving the least amount of blood flow.

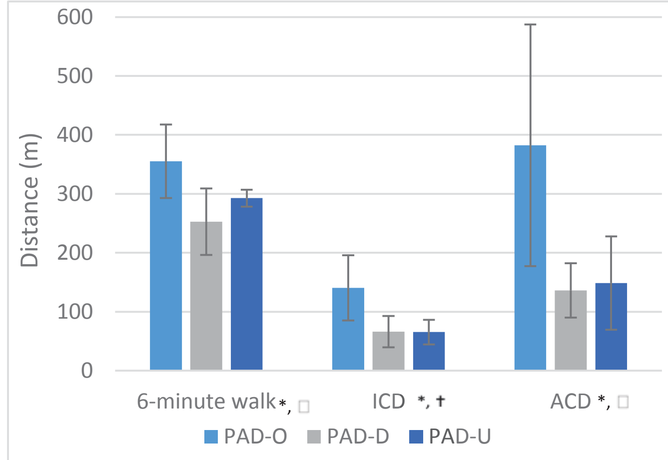

Figure 2: The significant interactions for the six-minute walk, and ACD. *Significance between PAD-O and PAD-D. ♀Significance between PAD-O and PAD-U.

Regarding co-morbidities, diabetes and foot ulcers seemed to affect the ankle variability parameters in opposite directions of the PAD-O groups. Reasons for this should be investigated further. Collectively, our results show diabetes and foot ulcers do affect gait differently from only having PAD.

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Table 1: Patient Demographics

Group	n	Age	Mass	Height
PAD-O	5	64.8 ± 3.49 yrs	86.07 ± 22.59 kg	174.66 ± 8.38 cm
PAD-D	3	65.33 ± 6.02 yrs	88.99 ± 12.84 kg	175.18 ± 2.76 cm
PAD-U	3	57.33 ± 5.51 yrs	86.41 ± 21.47 kg	179.53 ± 1.86 cm

DELIVERY OF VIBRATION TO THE RESIDUAL LIMB VIA THE PROSTHETIC SOCKET: PRELIMINARY INVESTIGATION OF SIGNAL INTEGRITY

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INTRODUCTION

Sensory deficits associated with lower extremity amputation are pervasive despite continued advancements in the field of prosthetics. Amputation above the foot and ankle not only results in mechanical and structural loss but also eliminates important cutaneous and proprioceptive pathways that aid the perception of both the environment and self-motion. The overarching goal of the current work is to investigate the stochastic resonance (SR) premise [1] as a means to maximize the sensory information gained through the socket interface. SR involves the application of a sub-threshold noise stimulus, which provokes threshold crossings that temporally emulate a weak underlying signal. This paradigm has been shown to be effective in improving sensation at the extremities and balance of older adults and individuals with peripheral neuropathy [2,3].

We intend to investigate the effect of delivering sub-threshold vibration to the residual limb via the prosthetic socket. Further, in a modification to the traditional paradigm, we intend to utilize vibration signals with a 1/f frequency spectrum (i.e. pink noise), based on the ubiquity of this structure in healthy biological signals [4]. We anticipate improvements in sensation, perception and function in the presence of sub-threshold socket vibration. Furthermore, we hypothesize that a pink noise structured signal will result in greater improvements over white noise as it emulates the structure of natural physiological processes and therefore may be more instinctively accepted and integrated.

Testing this premise hinges on the production and transmission of vibration with a specific frequency spectrum to the residual limb. The aim of this preliminary study was to determine the extent to which the amplitude and frequency content of vibration signals applied to the outer surface of the socket may be maintained during transmission through the socket.

METHODS

We tested the vibration produced by a commercially available tactor (Tactuator BM3C, Tactile Labs Inc., Montreal) in isolation with the tactor freely suspended, and then through a carbon fiber socket. White noise signals were produced using Audacity v2.1.2, converted into mp3 format and played through a digital voice recorder (WS-600S, Olympus Corp, PA) connected to the tactor. Vibration output was recorded using a uniaxial accelerometer (353B15, PCB Piezotronics, Inc., NY) connected to an oscilloscope (DS1102E, Rigol Technologies Inc., OR) via signal conditioner (480E09, PCB Piezotronics, Inc., NY). For the isolated condition the accelerometer was adhered directly to the suspended tactor using beeswax. Signals were examined over the 40-400Hz frequency range.

Initial testing of white noise signals in the freely suspended condition illustrated a non-linear response of the tactor at lower frequencies. Accordingly, envelopes were designed in Audacity to manipulate the frequency spectrum of the white noise signal being delivered to the tactor. Once a satisfactory white noise signal had been recorded from the suspended tactor, the signal integrity after transmission through the socket was tested. The tactor was mounted at three positions on the lateral side of the socket exterior. The socket was freely suspended and the accelerometer was secured to the inside of the socket at eight different positions using beeswax.

Root mean squared (RMS) amplitude and power spectra were calculated in Matlab (R2015a, The Mathworks Inc. Natick, MA).

RESULTS AND DISCUSSION

For the freely suspended tactor the refined envelope resulted in a signal with a flat frequency spectrum on observation (Figure 1) and a gradient of 0.08 on a power spectral density plot for the range of frequencies between 40-400Hz. When attached to the socket, the vibration signals recorded varied across different areas of the socket. Attenuation of the signal was observed at all tactor positions and recording positions with the exception of one combination, where amplification was observed (tactor at proximal position, accelerometer attached beneath it). The least signal attenuation overall was obtained with the tactor at the middle of the lateral side of the socket. Spectral properties of the signal were distorted at all tactor locations, with prominent peaks around 300Hz. It is unclear whether this is unique to this particular socket or will differ across prostheses.

CONCLUSIONS

Modifications to the spectral properties of the signal occur due to both the operating characteristics of the tactor and its transmission through the socket. Our next step is to perform testing on other prosthetic sockets to determine the consistency across prostheses of the distortions we have observed, and to determine an appropriate method of reinstating the required frequency spectra for both white noise and pink noise signals.

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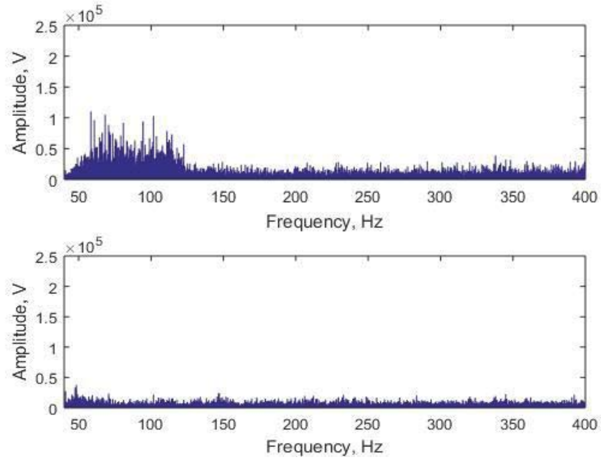

Figure 1: Suspended tactor output – frequency spectrum from 40-400Hz. Above – no envelope. Below – after adjustment.

Table 1: RMS signal amplitude as a percentage of RMS amplitude in isolated (suspended) condition

Tactor position	Accelerometer position – amplitude (%)			
		Lateral	Anterior	Medial
Distal	Distal	87.6	31.6	15.6
	Mid	80.0	-	75.2
	Proximal	64.9	41.3	21.9
Mid	Distal	61.5	33.0	21.0
	Mid	83.1	-	93.8
	Proximal	67.9	50.1	56.5
Proximal	Distal	58.0	44.3	23.0
	Mid	79.9	-	74.4
	Proximal	127.6	61.4	54.2

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VIRTUAL REALITY IN ELDERLY GAIT: EFFECTS OF SEMANTIC FLUENCY

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INTRODUCTION

Older persons have an increased risk of falling with nearly one-third experiencing a fall every year. Gait variability, indexed by sample entropy (SE) of step time, step length and step width, is correlated with increased fall risk in the elderly [1]. Sample entropy assesses the pattern or structure of the variability, with a higher value indicating a more random or unstable gait [2]. Gait variability is also related to decreased confidence in elderly individuals causing them to lower their physical activity levels which can ultimately lead to an increased risk of falls in the future [3]. Studies use virtual reality (VR) because optic flow environments have more ecological validity than static pictures. Experiments have found that under dual-task VR environments, elderly walkers, compared to healthy young, performed worse in both gait and cognitive load tasks [4, 5, 6]. The current study aims to explore differences in sample entropy values of elderly walkers while dual-tasking in a virtual reality environment.

METHODS

Twelve subjects, 65 and older, all right-handed, living independently in the community and free of any neurological diseases, depression or any diseases/disorders that may interfere with healthy cognition or walking, were asked and consented to participate in this study. Subjects completed three sessions, all approximately one week apart; the first session was a baseline session for the cognitive tasks (serial subtraction by threes, semantic and phonemic fluencies, reading, picture naming, the Stroop test, and dichotic listening tasks), while the last two sessions involved completing dual-tasks in the virtual reality lab, randomized to experience optic flow during their first dual-task session or last dual-task session. In the VR lab the subjects walked on a self-paced, split-belt treadmill (Bertec Corp., Columbus, OH) while completing cognitive tasks displayed on the screen via D-flow software (Motek Medical). There was also a walking-only control trial. The responses to the cognitive tasks in both the baseline and VR sessions were recorded through a headset microphone using Computerized Speech Lab software (CSL Model 4500, Kay Elemetrics Corporation). During the baseline session, the tasks were administered using the E-Prime 2.0 software (Psychology Software Tools, Pittsburgh, PA).

During the semantic fluency task participants are given three different categories and they are to name all of the words that they can think of that belong in the category. They cannot use proper nouns or synonyms. They did this for three minutes in each condition.

Gait data was collected by placing reflective markers in anatomical locations, specifically the Modified Helen-Hayes configuration. Marker position was recorded by an eight camera motion capture system (100 Hz; Vicon, Oxford, United Kingdom). Sample entropy of step length, step width and step time were obtained through a custom algorithm using MATLAB (MathWorks Inc, Natick, Mass) [2]. Data was analyzed using IBM SPSS Statistics for Windows (Version 22.0). Entropy and cognitive data were first checked for normality using the Shapiro-Wilk test. All gait data were then compared using paired samples t-tests and the data that violated the normality assumption was analyzed using the non-parametric Wilcoxon Signed Rank Test. Only step length for the optic flow walking condition was found to violate the normality assumption. Cognitive data were analyzed using a repeated measures ANOVA with conditions (base-line, VR, Non-VR) as factors.

RESULTS

There was a significant difference between step length entropy values of optic flow and non-optic flow conditions for the semantic task ($p = .011$); step width and step time were not significantly different. No significant differences were found for entropy values of step length, step width or step time between optic flow and non-optic flow conditions for the walking-only condition. Furthermore, no significant differences were found between the walking and semantic tasks for entropy variables in either condition.

No significant differences were found for correct number of responses in the semantic fluency cognitive task across all sessions ($p = .488$). However, participants averaged more correct words for the optic flow condition than in the non-optic flow condition and averaged more correct words in the baseline sessions as compared to both dual-task conditions.

DISCUSSION

Overall, except for step length in semantic optic flow versus non-optic flow conditions, there were no significant differences in entropy for the gait variables or the cognitive scores (Table 1). However, with the exception of step lengths in the walking and category optic flow conditions, average entropy values for the older adults were all above 1.50, suggesting a high level of irregularity in their gait. Also, the fact that step length was lower in the optic flow condition, corresponding to more regular gait, for the semantic task may suggest that subjects are constraining their gait, making it more automatic, in order to focus on the cognitive task, which they scored higher in.

The lack of substantial significant differences may be due to the characteristics of our older adult sample. Most participants were recruited from various health facilities, thus, they were relatively healthy and avid exercisers. Studies have shown that exercise benefits both cognition and motor skills, both of which were used in this study [7]. Future studies aim to have a wider range of subjects from different backgrounds and a larger sample size. The lack of significant differences found between dual-task sessions could indicate that older adults who exercise perform better on cognitively and physically demanding tasks, thus reducing their risk for falls in the future.

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Table 1: Average entropy values for step length, step width and step time.

	Optic Flow Walking	**Non-Optic Flow Walking**	**Optic Flow Semantic Fluency**	**Non-Optic Flow Semantic Fluency**
Step Length	1.45±.52	1.53±.33	1.21±.50	1.53±.19
Step Width	1.81±.12	1.82±.17	1.79±.13	1.73±.13
Step Time	1.77±.24	1.74±.25	1.74±.18	1.73±.30

Does Vibro-tactile Stimulation of the Vestibular System Influence Standing Postural Control?

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INTRODUCTION

The vestibular system is a complex structure of fluid-filled tubes and chambers that constitutes part of the inner ear. (Flint, 2010). The vestibular system functions to preserve posture, equilibrium, and body position in space, it also plays an imperative role in managing locomotion and other motions (Watson & Black, 2008). These vestibular signals might be critical for updating whole body representation while one moves in external space (Pfeiffer, 2014). Artificial vestibular stimulation in various forms including, galvanic vestibular stimulation (GVS) and vibro-tactile vestibular stimulation can be used to elicit a response in the vestibular system. (Mulavara 2011).

The purpose of this study is to investigate the potential changes in balance control in healthy young adults when stimulation of the vestibular system occurs via vibro-tactors. It is hypothesized that postural sway variability of the participants will decrease significantly when they are administered with vestibular stimulation during the Sensory Organization Test (SOT) compared to normal conditions.

METHODS

A group of 18 subjects, 11 male and 7 female ages 20.5 $\pm$ 1.04 years participated in the Sensory Organization Test (SOT) on Neurocom with and without vestibular stimulation. Stimulation was received via vibro-tactors placed on the subject's mastoid processes. The SOT is used to identify abnormalities in the subjects sensory system that contribute to postural control; somatosensory, visual and vestibular.

Six conditions were tested; 1) eyes open, fixed surface 2) eyes closed, fixed surface 3) eyes open, surrounding tilting about the medio-lateral axis 4) eyes open, surface tilting about the medio-lateral axis 5) eyes closed, surface tilting about the medio-lateral axis 6) eyes open, surface and surrounding tilting about the medio-lateral axis.

Subjects participated in each condition for three trials at three different tactile frequencies and with no stimulation. All conditions were randomized before the subject arrived. To ensure the participant's safety, all participants were strapped into a safety harness before administering tactile vibrations. In the case that a subject would get dizzy during any of these trials they would be given time to sit down and rest before continuing with the next trial.

RESULTS AND DISCUSSION

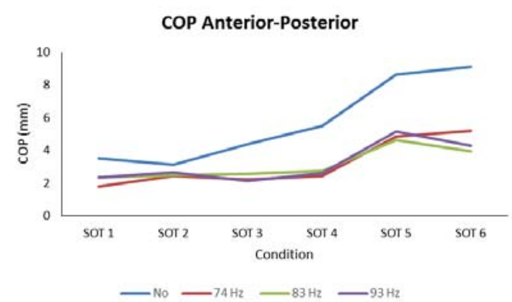

Figure 1. A significant main effect of the frequency used for tactors was observed in the root mean square (RMS) of center of pressure (COP) in the anterior-posterior (AP) direction (P<0.001). The RMS values in the AP direction were significantly higher for the no frequency conditions when compared to the conditions with different frequencies.

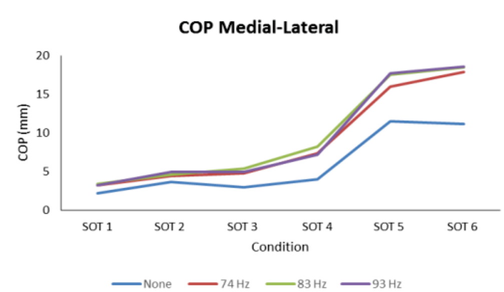

Figure 2. A significant main effect of the frequency used for tactors was observed in RMS of COP in the medial-lateral (ML) direction ($p>0.001$). The RMS values in the ML direction were significantly lower for the no frequency conditions when compared to conditions with different frequencies.

CONCLUSIONS

Vibro-tactile stimulation on the mastoid process did have an effect on standing posture in the AP and ML direction. This effect could be due to perturbing the vestibular system or by stimulating the proprioceptors of the neck. The tactor placement on the left and right mastoid processes could explain the increase in RMS values in the ML direction, and decrease RMS values in the AP direction. Future studies will include sub threshold stochastic frequencies that may optimize signal strength in the vestibular system and improve balance control.

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The relationship between perceived health outcomes and gait improvement following surgical intervention in peripheral arterial disease.

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INTRODUCTION

Health attitudes regarding quality of life and the potential for recovery of function are related to treatment improvement levels in some populations[1]. Patients with peripheral arterial disease (PAD) experience reduced quality of life and physical function from insufficient leg blood flow. The limited blood flow is caused by atherosclerotic blockages in the arteries in the legs. Muscular ischemia causes pain during walking, eventually forcing patients to stop to rest. The standard treatment to improve blood flow in patients with PAD is surgery. In this population, it is unknown how perceived health outcomes prior to surgery influences surgical outcomes. Thus, this project will determine whether a relationship exists between perceived health status, assessed through questionnaires, and improvement in gait biomechanics and maximum walking distances following surgery. If perceived health outcomes are positively related with improvements post surgery, educational and counseling programs to inform patients about the potential for improve health could potentially improve the level of improvement in gait and walking distances post surgery.

METHODS

Thirty patients diagnosed with PAD (age: 62 ± 5.38 years; ht: 174.70 ± 7.12 cm; mass: 85.28 ± 16.57 kg) were consented and referred to the Biomechanics Research Building for this study. Patients were having surgery as the standard of care and they participated in additional research evaluations before and six months following revascularization intervention. Perceived health outcomes were assessed using the Walking Impairment Questionnaire (WIQ)[2] and the Medical Outcomes Study Short Form 36 Healthy Survey (SF-36) [3] The WIQ is a disease-specific questionnaire for individuals with claudication and the SF-36 questionnaire evaluates health status across domains and has been validated in multiple populations. The scores from domain for both instruments are included as reflective of separate areas of perceived health outcomes.

Functional outcomes were assessed by measuring gait biomechanics and maximum walking distances. Initial and absolute claudication distance were determined using the Gardner treadmill test. This , is the research standard to measure function in patients with PAD. In this test, patients walked on a treadmill set at 0.89 m/s (2.0 mph) and 0% grade, increasing by 2% grade every two minutes[4] . The first indication of pain was recorded as the initial claudication distance and the total distance the patients can walk on the treadmill before stopping because of pain was the absolute claudication distance. For gait biomechanics, five trials of overground walking data were collected using a 12-camera motion capture system (60 Hz; Motion Analysis, Santa Rosa, CA, USA) synchronized with force plates (600 Hz; AMTI, Watertown, MA, USA). Data were collected prior to the onset of claudication pain. Kinematic and kinetic data were calculated using the methods of Nigg et al and Vaughan utilizing Visual 3D (C-Motion, Germantown, MD)[5,6].

Improvements in walking distance and gait biomechanics discrete points were calculated by subtracting baseline data from post surgery data. Pearson's correlations were used to determine the strength, direction, and significance of the relationship between individuals perceived health outcome variables and functional outcome variables.

RESULTS AND DISCUSSION

Significant findings were found in 11 categories ($p < .05$) using Pearson's correlations. Specifically, absolute claudication distance, six minute walking distance and ankle plantar flexion moments were related to perceived functional outcomes determined from the patient questionnaires. Table 1 shows the Pearson's correlation coefficients for these 11 domains. Only moderate relations were found. The largest coefficients of correlation were found for the SF questionnaire of physical function and six-minute walking distance ($r = -0.525$, $r^2 = 0.276$), physical function and ankle plantar flexion moment ($r = -0.502$, $r^2 = 0.252$), and pain and ankle plantar flexion moment ($r = -0.448$, $r^2 = 0.201$).

CONCLUSIONS

The purpose of this study was to examine if there was a relationship between patient's expected health outcomes and physical function following corrective surgery. Based on these results we cannot say that there is a strong relationship between these variables. The strongest relationship we found could only account for 27.6% of the variance. This tells us that our model was not a strong predictor of the relationship between expected health outcomes and physical function.

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Table 1: Pearson's correlation coefficients for significant variables.

	ACD	Six-MWD	Ank_PF_Mom
SF: Physical Function		-0.525	-0.502
SF: Limitation due to Physical Health			-0.386
SF: Limitation due to Emotional Health			-0.404
SF: Pain	0.48	0.-372	-0.448
SF: Social Functioning			-0.383
SF: General Health		-0.387	
WIQ: 1		-0.407	
WIQ: 2		-0.412	

Designing a More Versatile Cap for Monitoring Brain Activity

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INTRODUCTION

Our goal for this project is to design and test a more versatile cap and probe mounting system that is also more comfortable. There are two main objectives to this project:

1. Make the device more comfortable to subjects
2. Make the device more versatile

The Biomechanics Research Building (BRB) is presently using functional near-infrared spectroscopy (fNIRS) to measure and understand brain activity during human movement. FNIRS is superior to other devices of its kind because it:

- Allows researchers to attain moving data from subjects.
- Researchers can target specific lobes of the brain to study.
- Various filtering techniques lead to more precise data.

As illustrated in Figure 1, fNIRS attains data by working with pairs of probes. As illustrated in the figure below, one of the probes shoots the infrared light that measures the concentration of oxygen in the blood, then the other probe receives it (Psych Central).

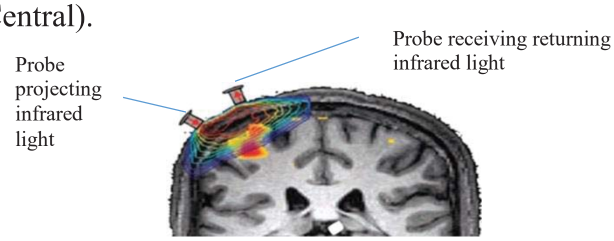

Figure 1: Illustration of how fNIRS collects data
http://www.researchimaging.pitt.edu/content/near-infrared-spectroscopy-nirs-brain-imaging-laboratory

METHODS

Our main approach to resolve these problems is to create a new cap entirely. We will achieve this by:

- Raising the probes in order to allow contact only between the spring-loaded portion of the probe and the scalp.
- Create a cap with a more flexible body.

While this new cap is being produced, a temporary fix involving small quarter inch spacers are being used (Figure 2):

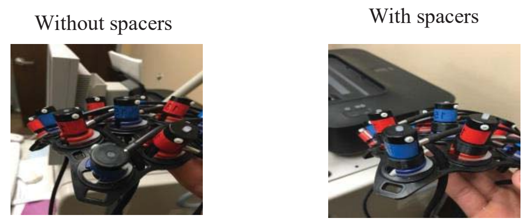

Figure 2: A comparison of the current device with and without the spacers installed

We are currently experimenting with using a soft plastic such as nylon to introduce flexibility throughout the cap and achieve objective two, making it more versatile (Figure 3). By keeping the new device (left) flexible, it will have the variability to fit the contours of each subject's skull.

Figure 3: The new device prototype compared to the currently used device

RESULTS AND DISCUSSION

The new prototype will be compared to the old device by a series of experiments. These experiments will compare the data readings of oxygenated and deoxygenated blood to a specific area of the brain with both the new and old fNIRS devices. We plan to collect data to analyze the comfort levels of the participants, and the quality of data being obtained by the new prototype of the device.

CONCLUSION

Future direction of Objective 1:
We plan to continue to attain and process more data from multiple subjects in testing the effectiveness and comfort of this new device. The spacers will be used until a fully functional cap is produced. They serve as a way of testing the concept of the future device.

Future direction of Objective2:
In an effort to make the cap more versatile, we plan to experiment with more materials than just nylon to find which is best suitable for our goals of the new device. As well as finding the perfect material, we will also be experimenting on ways to make the cap adjustable to each participant's skull shape and size.

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VARIABILITY ANALYSIS OF WALKING WITH CONTINUOUSLY INCREASING ASSISTANCE FROM A SOFT EXOSUIT

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INTRODUCTION

Recently, multiple groups showed that it is possible to reduce the metabolic cost of walking with portable exoskeletons [1,2] or exosuits [3]. While these devices could be used for overground walking they still have to be further optimized to become more practically useful. Studies from the field of exercise physiology suggest that optimization protocols with continuous parameter changes can be less time consuming and allow to investigate more parameter settings than steady state protocols. However, when using this method for optimizing a wearable device it could be that the additional actuation variability perturbs the wearer. In fact, studies with robotic ankle prostheses have suggested relationships between actuation variability and metabolic cost [4]. To understand the isolated effect of continuously changing actuation magnitude we compared results from a condition where actuation magnitude continuously increased versus a condition with steady-state actuation.

METHODS

7 participants walked on a treadmill at 1.5 m s^{-1} wearing a soft exosuit that assists plantarflexion and hip flexion (Figure 1A). The assistance profile used position control to achieve different target peak forces [5]. In a *ramp* condition, the target peak force delivered at the ankle continuously increased from 0 to 75% body weight over 10 minutes (Figure 1B). In a *step* condition, participants walked in a series of five-minute steady-state conditions with five target peak forces between 0 and 75% of body weight [6,7]. At the end of each gait cycle the exosuit controller slightly modified the amount of retraction of the cable for the next gait cycle based on the error between the desired and the actual peak force. While this iterative control scheme tries to minimize the error in the peak force based on each previous gait cycle it does not predict the effect of the human variability for the next gait cycle. The actual peak forces are a result of the motor position as well as human kinematics. So if the controller remains the same then changes in peak force variability indicate changes in human variability. To evaluate the evolution of inter-stride variability in the peak force during the *step* conditions as well as the entire *ramp* condition, we calculated inter-stride standard deviation over a moving window of 30 strides [7]. However, it is expected that some portion of this standard deviation is due to the slope of the *ramp* rather than an intrinsic increase in variability. In order to evaluate variability isolated from the slope of the *ramp* we also calculated the 30-stride standard deviation of the first-difference as described in [7]. To compare these two types of variability metrics between the *step* and *ramp* conditions we fitted the results with second order polynomial regression versus peak assistive force and evaluated significance differences at the five force levels of the *step* condition.

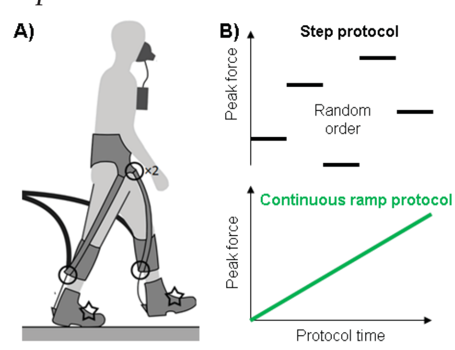

Figure 1: A) Exosuit, **B)** *Ramp* and *step* protocol

RESULTS AND DISCUSSION

Figure 2A shows higher inter-stride standard deviation in assistive peak force over a moving window of 30 strides in the *ramp* conditions at the lowest two force levels. However, after de-trending using the first difference method there were no more significant differences between the *ramp* and *step* condition (Figure 2B). This absence of increased variability after detrending for *ramp* slope suggests that participants were not perturbed by the slow linear increase peak force. This echoes results from a recent split-belt study where it was assumed that participants are well capable at tracking treadmill speed perturbation changes when they are implemented in a gradual way as in the *ramp* condition [8].

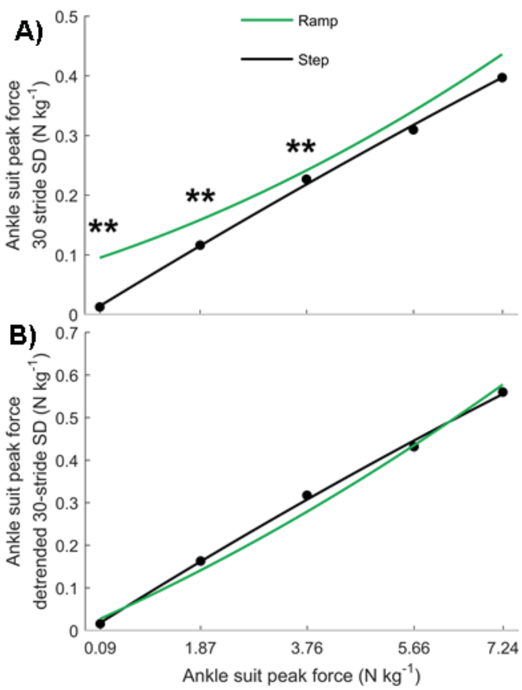

Figure 2: Inter-stride variability of ankle suit peak force. A) Standard deviation over a 30-stride window. **B)** Standard deviation after detrending using the first-difference method [7]. (** $p < 0.01$)

CONCLUSIONS

The variability analyses shown here indicate that a slow continuous parameter change does not cause additional biomechanical variability. Consequently, such continuous parameter sweep can also be used as a faster alternative than a discrete *step* protocol for mapping variability as a function of actuation parameter values. In separate analyses, however, we have found that metabolic results can be different between a continuous parameter sweep and discrete *step* protocol [6]. Future analyses involving non-linear variability measures as described in [9, 10] could be useful to further investigate if there are changes in variability between continuous *ramp* sweeps and discrete *step* protocol.

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COMPARISON OF WII BALANCE BOARD AND LABORATORY GRADE FORCE PLATE FOR THE MEASUREMENT OF SWAY DURING STANDING

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INTRODUCTION

Measurement of standing balance can be useful for determining functional ability and risk of falling [1]. While laboratory-grade force plates provide accurate information, they are not always accessible for clinical testing. The Wii Balance Board (WBB; Nintendo, Redmond, Washington, USA) is an inexpensive, portable, and widely available device that has shown potential as an alternative measurement tool for the clinical environment. Previous studies have shown good consistency between WBB- and force plate-derived measures of balance based on quantification of the magnitude of sway, e.g. range, sway path [2, 3]. However, validation of measures that quantify the temporal structure within the sway patterns during standing balance is lacking. Detrended Fluctuation Analysis (DFA) is one such example. DFA evaluates the extent to which patterns within a time series are self-similar, i.e. patterns repeat themselves at shorter time scales. The scaling exponent it produces, α, reveals the presence of long range correlations, and alterations to this value within biological signals have been linked to disease and aging [4].

The purpose of this study was to compare the values of α calculated from WBB data with those calculated using a laboratory-grade strain-gage force plate (FP) (OPTIMA, AMTI Inc., Watertown, Massachusetts, USA) to determine whether the WBB is a suitable alternative device for the measurement of temporal structure within sway.

METHODS

The WBB was interfaced with a laptop computer (Dell Latitude, Windows Vista) using open source code (available at: http://www.colorado.edu/neuromechanics/research/wii-balance-board-project) and calibrated in accordance with the stated protocol. The WBB was placed centrally on the FP to enable simultaneous capture of identical standing trials. Both devices were zeroed once located. Sampling frequencies of the WBB and FP were set to 30 Hz and 600Hz respectively.

Three healthy subjects completed bilateral standing trials with eyes open (EO) and with eyes closed (EC). Subjects were instructed to stand calmly while focusing on a black cross at eye level. Prior to collection for the first trial, subjects' feet were outlined in order to reduce variability of stance across trials.

Three minutes of data were extracted from each trial. FP data were down-sampled to 30Hz for all calculations. Anteroposterior (AP) and Mediolateral (ML) root mean square position (RMS), range and DFA α were calculated for each subject and condition from the center of pressure trajectories captured by the two devices.

RESULTS AND DISCUSSION

RMS results from the WBB were within 0.25mm of the FP in both AP and ML directions. Range values from the WBB data were within 2.1mm of the FP values in both AP and ML directions.

DFA showed good consistency in α values in both the AP and ML directions (Figures 1(a) and (b) respectively) in both EO and EC tasks for the two measurement devices. In DFA values between WBB and FP, there was less than 0.2% difference in the AP direction and less than 1.9% in the ML direction.

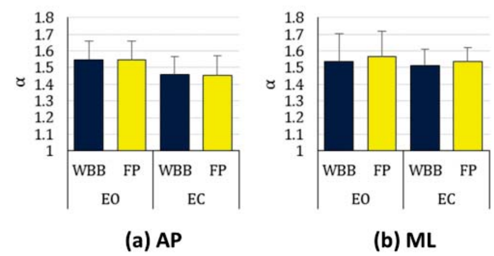

Figure 1: DFA α values for sway in (a) anteroposterior (AP) and (b) mediolateral (ML) directions during standing. Differences in sway patterns between eyes open (EO) and eyes closed (EC) trials are captured simultaneously across devices.

CONCLUSIONS

The results of this preliminary study are promising and suggest good consistency between the easily-accessible WBB and laboratory-grade force plates for the quantification of the temporal structure of sway by DFA. Testing in a pathological population is now warranted in order to determine whether this consistency is maintained in the measurements of postural sway patterns that may differ qualitatively from those of healthy young adults.

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MEASURING COUPLING OF BREATHING AND GAIT RHYTHMS USING CROSS SAMPLE ENTROPY

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INTRODUCTION

It has long been suggested that various biological rhythms exhibit some degree of synchrony, and that stepping frequency if often a submultiple of the breathing frequency [1,2]. Coupling of breathing and stepping rhythms is considered present when the interval between walking and breath events is constant for a series of breaths [2].

Chronic Obstructive Pulmonary Disease (COPD) is characterized by persistence airflow limitation [3], altering breathing patterns and timing, which may in turn effect walking patterns. Many tools are available to assess coupling of different signals, however the nonlinear characteristics of walking and breathing patterns suggest that a nonlinear measure would be preferable.

Cross sample entropy (xSE) was developed from sample entropy which was in turn developed to the overcome perceived limitations of approximate entropy [4] as a way to compare nonlinear signals. xSE measures the likelihood that patterns that are observed in one signal can also be found in another signal. (Figure 1)

The purpose of this study was to assess the coupling of breathing and walking patterns of persons, with and without COPD, using xSE. It was hypothesized that persons with COPD would exhibit lower xSE, indicating more closely coupled breathing and walking rhythms.

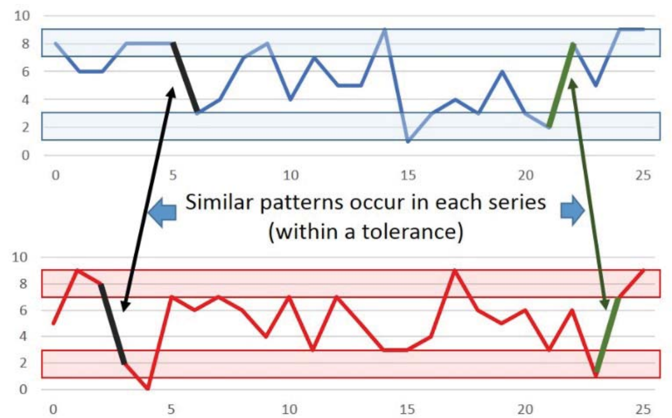

Figure 1. xSE is a measure of the probability that a pattern that occurs in one time series will also occur in another time series

METHODS

Six patients with COPD and 12 healthy older controls were recruited for this IRB approved study. All subjects signed informed consent prior to participation. Subject details are shown in table 1.

Subjects walked on a treadmill for 4 minutes at 5 speeds (self-selected speed (SSS), ±10%, ±20%). Breathing data were recorded using a wireless physiological monitor (Bioharness™ 3, Zephyr Technology Corp., Annapolis, MD) at 18Hz. Vertical movement of the right greater trochanter was simultaneously recorded at 60Hz using a 6-camera motion capture system (Motion Analysis Corp., Santa Rosa, CA). Breathing data were resampled to 60Hz. xSE values were calculated for each breathing/trochanter data series using the method described by Richman et al. [4], using $r = 0.20$ and $m = 2$.

Table 1. Demographics of subjects

Group	N	Age (yr)	Height (m)	Weight (kg)	Gait Speed (m/s)
COPD	6	63 (10)	1.8 (0.9)	109.7 (40.1)	0.8 (0.1)
Controls	12	66 (11)	1.8 (0.9)	80.9 (15.0)	1.2 (0.3)

RESULTS

The values of xSE calculated for each group in shown in figure 2. No significant differences in xSE were found between the groups at all speeds except the lowest speed conditions. Patients with COPD walking at a speed 20% slower than their SSS had a significantly lower sample entropy ($p = 0.029$) than healthy age-matched subjects walking with the same level of reduced speed. At all other speeds, xSE was not different between patients and healthy control subjects.

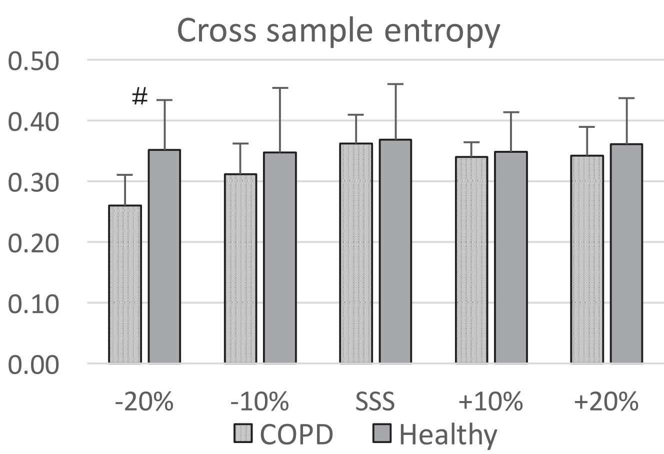

Figure 2. Cross sample entropy of COPD and healthy subjects walking at self-selected speed (SSS) and speeds ±10% and ±20% of SSS.

DISCUSSION

Higher xSE values are expected when the pattern of one signal is not repeated in a similar fashion on another signal. Healthy subjects would be expected to continuously make small adjustments to breathing and walking patterns across a broad range of breathing frequencies and walking speeds.

Patients with COPD are not expected to have the same level of adaptability of their breathing patterns as healthy subjects. If their level of walking adaptability is also not as great and these more rigid patterns are dissimilar, this may be the cause xSE values that are of similar magnitude to those of healthy subjects. For patients with COPD the lower xSE value may be indicative of more closely matched breathing and walking frequency's where the pattern of breathing is able to more closely match that of walking.

CONCLUSIONS

The results from this study appear to indicate that healthy older adults are able to adapt their breathing patterns to changes in walking patterns similarly across a range of walking speeds. Patients with COPD however do not appear to have the same consistency across of coupling across walking speed. At the slowest walking speed, lower demands may concede more flexible walking patterns, allowing them to more closely follow the somewhat fixed breathing pattern which is indicated by the lower xSE.

Further investigation using other nonlinear measures of coupling will provide a better insight into the interplay between the breathing and walking patterns of patients with COPD. This will give a better understanding of how walking is affected by COPD.

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Relationship Between Posturography and The Gross Motor Portion of The Mullen Scales of Early Learning in Infants.

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The Mullen Scales of Early Learning (MSEL) is a standardized, valid, and reliable general developmental measure from birth to 68 months of age. MSEL can be used to assess cognitive and motor abilities. The scales have been utilized a great deal recently to evaluate gross motor behavior in infants at risk for autism. The MSEL is a subjective and non-quantitative evaluation of gross motor behavior. However, recent experimental paradigms may provide an objective method of evaluating gross motor function. Sitting postural control is a fundamental gross motor skill that can be examined in infants during sitting. Thus, the purpose of this study was to evaluate the relationship of the gross motor portion of the MSEL with an objective method, such as sitting posturography. Seven typically developing infants were evaluated at 6 months of age, when they could sit independently for at least 10sec. Center of pressure was collected for three trials of 10sec. Linear and nonlinear measures were used to evaluate sitting postural sway. Linear measures included: root mean square (RMS), range in the anterior/posterior (AP) and medial/lateral (ML) directions, as well the sway path. We also computed the sample entropy (SampEn) in both directions. For statistical analysis we computed simple linear correlations with each of the postural variables and the MSEL motor T scores. The findings showed that only RMS ($r=-0.749$) and Range ($r=-0.866$) in the ML direction had a strong negative correlation with the MSEL motor scores. However, SampEn in the ML direction had a moderate positive correlation with the MSEL motor scores. Infants that had greater MSEL motor scores have lower Range and RMS values in ML direction and infants that had lower MSEL motor scores had greater Range and RMS values in ML direction. In contrast, infants that had greater MSEL scores had greater SampEn values in the ML direction, whereas infants that had lower MSEL scores had lower SampEn values in the ML direction. It is evident that the MSEL motor score seems to capture better ML posture behavior than AP.

THE FORM AND STABILITY OF VISUOMOTOR COORDINATION IS AFFECTED BY THE STRUCTURE OF THE ENVIRONMENT

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INTRODUCTION

The coordination dynamics approach has been used to understand a variety of coordinated motor behaviors, from postural control and locomotion (Brady et al, 1999; Diedrich & Warren, 1995), to coordinated arm movements (Haken, Kelso, Bunz, 1995), and language production (Fowler & Saltzman, 1993). The predictions of coordination dynamics are derived from the HKB model (Haken, Kelso, Bunz, 1995). The predictions of this model can be derived from the following motion equation:

$$\dot{\phi} = \Delta\omega - a\sin(\phi) - 2b\sin(2\phi)$$

where ϕ models the relative phase of the coordinated elements and the over dot denotes differentiation with respect to time.

HKB Prediction 1: Stable modes of coordination exist at $\phi = 0^\circ$ and $\phi = 180^\circ$.
HKB Prediction 2: If coordination is initially prepared at $\phi = 180^\circ$, a spontaneous transition to $\phi = 0^\circ$ is expected as collective frequency (modelled as b/a) increases.
HKB Prediction 3: When asymmetry (modelled as $|\Delta\omega|>0$) is present, a shift in relative phase away from either $\phi = 0^\circ$ and $\phi = 180^\circ$ will be observed (e.g. from $\phi = 0^\circ$ to $\phi = 20^\circ$). Also reduced stability of the fixed point is predicted.

Here we investigated the task of coordinating arm movements with a visually displayed oscillating dot (Figure 1A). We test the hypothesis that a spatial misalignment of the frames of reference involved in this task (Figure 1C) will introduce an asymmetry into the coordination dynamics. We hypothesize that this asymmetry will be visually specified. We consequently predict that the asymmetry will be observed in a complex visual environment condition (Figure 1A), but not in a minimal visual environment condition (Figure 1B).

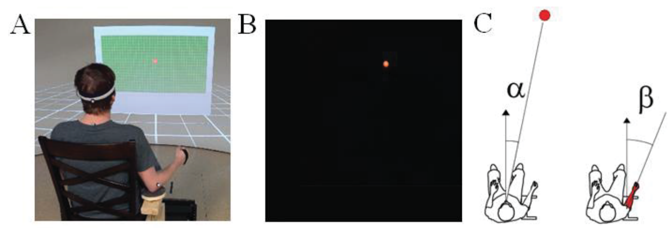

Figure 1: Experimental setup. A) Complex visual environment. B) Minimal visual environment. C) Angles of oscillation of dot motion (α) and arm motion (β).

METHODS

Ten participants coordinated their arm with an oscillating visual stimulus. Coordination was between movement of the arm (α) and movements of the oscillating stimulus dot (β). In the complex visual environment, condition sight of the arm and the oscillating dot was possible. In a minimal visual environment condition, all lights were turned off and only the motion of the stimulus was visually perceivable.

Each trial began with the stimulus oscillating at 0.5 Hz. The collective frequency of oscillation (CF) was increased in stages of 0.1 Hz to 2.5 Hz. Each stage lasted for 10 seconds. Participants were given instruction to start the trial coordinating in either in-phase ($\phi = 0^\circ$) or anti-phase ($\phi = 180^\circ$) pattern. There were no restrictions on how coordination was to be performed after the start of the trial.

RESULTS

Consistent with HKB prediction 1, grand distributions of relative phase across all participants were found to be bimodal and to produce peaks at close to $\phi = 0^{\circ}$ and $\phi = 180^{\circ}$.

Figure 2 shows the distribution of ϕ as a function of CF for trials in which participants were initially prepared at $\phi = 180^{\circ}$. The results are consistent with HKB prediction 2. The locations of the peaks in the ϕ distributions were used as a gross measure of mean location of each coordination mode at each CF. These mode peak locations are shown as red markers in Figure 2 and 3.

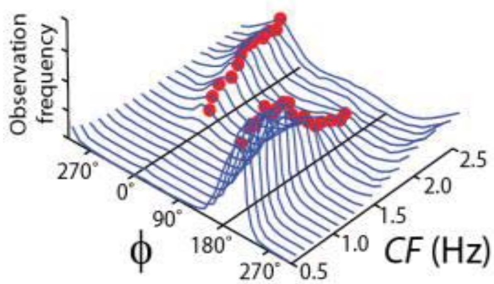

Figure 2. See text for details.

Mode peak locations across all conditions are depicted in Figure 3. These results suggest that in the complex visual environment condition the location of mode peaks was shifted away from $\phi=0^{o}$ and $\phi=180^{o}$, and was shifted to a greater degree as CF increased. In contrast no such shift is visible in the minimal visual environment condition.

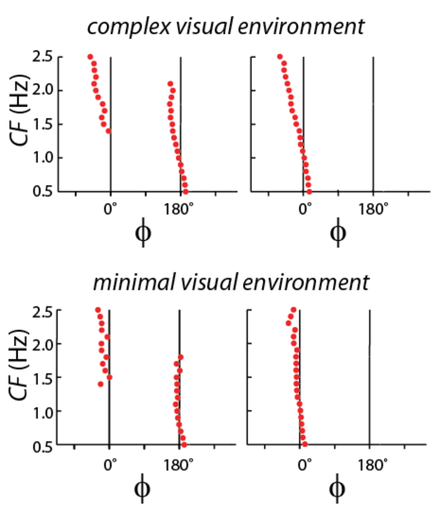

Figure 3: Mode peak locations for initially anti-phase (left) and initially in-phase (right) preparations for the two visual environment conditions.

CONCLUSION

The HKB model predicts (HKB predication 1) that task relevant asymmetries are will result in shifts in the location of stable modes of coordination away from $\phi = 0^{\circ}$ and $\phi = 180^{\circ}$. Consistent with these results we found that misalignments of effector motion and stimulus motion produced asymmetries in coordination. Interestingly, the observed increase in mode peak shift with CF is not straightforwardly predicted by the HKB model.

The HKB model also predicts that a decrease in stability will accompany the shift in mean ϕ away from $\phi = 0^{\circ}$ and $\phi = 180^{\circ}$. We are currently investigating this prediction. To better understand these results we plan to calculate the mean ϕ and standard deviation of ϕ for in-phase and anti-phase modes.

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STRIDE-TO-STRIDE VARIABILITY IS INFLUENCED BY PUSH-OFF MECHANICS DURING HUMAN WALKING

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INTRODUCTION

Human walking is not just a periodic movement as subtle variations exist from one step to the next. This variability has a unique pattern that is characteristic of healthy gait [1]. The mechanism of these stride-to-stride fluctuations could be influenced by the magnitude of propulsive (push-off) force [2] and may be a result of coordinated actions of the neuromuscular control and inherent limb push-off mechanics.

Passive dynamic walking models have begun to shed new insights onto the factors underlying stride-to-stride fluctuations. Such models have identified the step-to-step transition as an important determinant of economical movement that facilitates forward movement [1]. A model developed by Kurz and Stergiou has shown that the stride-to-stride fluctuation is influenced by the magnitude of propulsive (push-off) force [3]. This finding may indicate that the stride-to-stride fluctuations may be inherently linked to the push-off mechanics.

The purpose of this study was to determine the link between push-off mechanics and stride-to-stride fluctuations during walking. We experimentally created a unilateral push-off deficiency by immobilizing the ankle joint on one side. This effect is expected to diminish the propulsive function of the immobilized ankle, since the ankle plantar flexors are the primary source of push-off force and work production [3]. We hypothesized that the unilateral ankle immobilization would change the stride-to-stride fluctuations during human walking.

METHODS

Kinematic (Vicon, Oxford Metrics, Oxford, UK, sampled at 100 Hz) and kinetic (Bertec corporation, Columbus, OH, USA, 1000 Hz) walking data were collected from two healthy adults (2 males, 87.76 kg, 1.79 m). The participants had no history of lower extremity musculoskeletal injury or surgery or neurological disorder. We used a standard walking boot to immobilize the ankle-foot structures, limiting its ability to generate mechanical power/work during push-off. Each participant walked at a fixed speed of 1.25 m/s on an instrumented split-belt treadmill for two trials lasting 5 minutes: walking with normal shoes, and walking with restricted ankle (an ankle boot on one side).

We quantified the pattern of stride-to-stride fluctuations of the ankle angle kinematics using the largest Lyapunov Exponent [4]. An increase in the largest Lyapunov Exponent indicates higher divergence in the stride pattern (i.e., each stride is dissimilar to the previous stride), whereas a decrease indicates lower divergence (i.e., each stride is more similar to the previous stride).

We also quantified the mechanical power of foot-ankle structures using a unified deformable segment analysis [4]. We computed the total positive work by integrating mechanical power with respect to time.

Between the two walking trials, we compared the largest Lyapunov Exponent of the ankle joint of the unrestricted ankle on the trial involving the boot, and the same ankle during normal walking. We also compared the total positive work done by the ankle-foot structures on the restricted ankle during the trial involving the boot, and the same ankle during normal walking.

RESULTS AND DISCUSSION

The ankle boot reduced push-off capacity during walking. This is indicated by a 64.5% reduction in total ankle-foot positive work (Fig. 1) during walking with the boot, compared to normal walking. This reduction in unilateral push-off work corresponded to a 23.1% increase in largest Lyapunov Exponent in the contralateral (unrestricted) ankle. This result supports our hypothesis that reduced ankle push-off may regulate stride-to-stride fluctuations during walking.

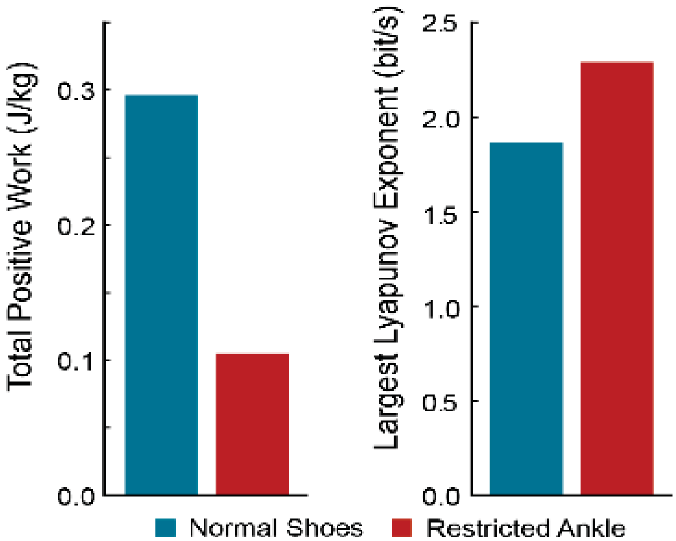

Figure 1. Left: Total ankle-foot positive work was reduced during restricted ankle condition (i.e., walking with boot on one side) compared to normal shod walking. **Right:** Largest Lyapunov Exponent for the unrestricted ankle was greater in the restricted ankle condition (red) compared to the normal shod condition (blue).

CONCLUSIONS

Our preliminary investigation supports the idea that the stride-to-stride fluctuations during human walking may be inherently linked to propulsion mechanics. We are currently collecting data on more subjects to confirm these initial observations. Our findings may be broadly applicable to enhance our understanding of the mechanism of human movement variability, as well as gaining new insights for movement pathology. For example, individuals with lower limb amputations exhibit abnormal stride-to-stride fluctuations [5]. These individuals also show impaired propulsion due to reduced push-off work of the prosthetic limb [6]. It may be possible that the abnormal stride-to-stride fluctuations in these individuals can be attributed to impaired push-off mechanics. We are currently exploring the role of prosthetic limb push-off in regulating the stride-to-stride fluctuations.

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Virtual reality augments learning of the spatial components of a gait coordination task differently for each leg.

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During split-belt treadmill walking the sensorimotor system must adapt to a novel set of constraints. The visual input is a rich source of information that can influence the split-belt adaptive process. Magnitude and temporal structure are two aspects of variability that can provide complimentary information about a movement pattern. Exploring how these measures change in response to split-belt walking can help characterize the neuromuscular control that is involved in locomotor adaptation.

Methods: 20 participants walked on a split-belt treadmill in both tied-belt and split-belt conditions: 10 participants walked in a virtual reality (VR) environment and the other 10 walked blindfolded (BF). Three 5-minute split-belt conditions were conducted where the right belt moved at twice the speed of the left belt. A virtual moving corridor was provided to the VR participants at the speed of the slow belt. Coefficient of variation and entropy were calculated for step length and step time. The baseline values from the tied-belt were subtracted from the first split-belt trial to represent early adaptation and the last split-belt trial to represent late adaptation. These measures were calculated for 200 step lengths and times on the right and left legs.

Results: For step length the VR condition resulted in an increase in coefficient of variation (P = .007) and a decrease in entropy (P = .004) for the fast leg during early adaptation, which returned to baseline values in late adaptation. The BF group showed no change across conditions. Step time did not show differences between the VR and BF groups for either leg.

Discussion: During early adaptation the spatial component of the fast leg had greater overall variability which happened in a more ordered manner. This could indicate a freezing of the degrees of freedom while adapting to the new locomotor pattern. Interestingly this phenomenon was not seen on the slower side or when the participants were blindfolded. There was also no difference in the temporal component for either leg between the VR or BF groups. In the BF group sensory reweighting would result in a higher proprioceptive gain, which may have allowed adaptation to the split-belt walking pattern without altering the spatiotemporal characteristics of either leg. However, in the VR group the visual flow matched the slow leg but was incongruent with the fast leg. This resulted in the fast leg exhibiting altered spatial characteristics while learning to calibrate to an incongruent visual flow. These data highlight the importance of visual information on sensorimotor adaptation in a novel walking task, and suggest that VR must be created in a manner that evokes the desired response.

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PUSHOFF WORK IS INCREASED FOLLOWING PROSTHESIS ADAPTATION

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INTRODUCTION

After undergoing amputation, patients must relearn to walk with new movement strategies integrating a prosthesis into their normal biomechanical system. Key factors in this recovery are effective prosthesis prescription and the patient's utilization of their prosthesis. Prosthetic utilization is of particular importance, because of a tendency for individuals with amputation to increase loading on the intact limb [1] instead of distributing load to the prosthesis side. Intact limb over-reliance could contribute to secondary problems seen in these individuals [2].

There is a lack of knowledge on how individuals adapt to a new prosthesis. Many studies exist comparing different prosthetic feet and individuals with amputation to intact controls [3], but few have investigated these individuals' gait over time. A better understanding of how gait behavior changes over the course of adapting to a new prosthetic device may give clues towards patient outcomes. Clinicians may use visual gait evaluations to guide rehabilitation, but there is a need for objective measures to quantify the process of adaptation. Mechanical power and work profiles are a prime subject of analysis for modern energy-storage-and-return type prosthetic feet. In this context, the amount of energy a prosthesis stores and returns (i.e., positive and negative work) during stance is directly related to how a user loads and unloads the prosthetic limb, and may change over the course of adaptation.

The purpose of this study was to observe and quantify how energetic profiles of individuals with amputation change over a three week period of adapting to a new prosthetic foot. We hypothesized that after a period of adaptation, positive and negative work done by a patient's prosthesis would increase. Additionally, we hypothesized that positive work done by the intact side ankle-foot system would decrease. These changes would possibly reflect increased utilization of the new prosthetic foot from initial fitting.

METHODS

Kinematic and kinetic data were analyzed retrospectively from subjects previously recruited for an earlier study [4]. Twenty two subjects (age 50.3 ±15.1 years, height 177.3 ±8.2 cm, mass 101.5 ±19.0 kg, time since amputation 7.5 ±6.0 years, residual limb length 15.7 ±3.6 cm) with unilateral, transtibial level amputation (14 traumatic, 5 vascular, 3 other) were recruited from a local clinic. Subjects were given a new "high-activity" passive prosthetic foot component at their same Medicare functional classification level (K3 or K4). Subjects wore the foot for three weeks as their daily prosthesis. Instrumented gait analysis was performed at three visits in the adaptation period: at initial fitting (0 weeks adaptation), halfway (1.5 weeks), and at the end (3 weeks). Subjects were aligned for the new foot by a certified prosthetist at initial visit. Overground walking trials were performed over an embedded force plate (sampled at 600 Hz: Kistler, Amherst, NY) at a self- selected speed, after which 10-15 steps were extracted for analysis. Kinematic data was recorded with a 12 camera system at 60 Hz (Motion Analysis Corp., Santa Rosa, CA).

Prosthesis power and work were quantified using a unified deformable segment model [5], shown to more accurately capture energetics of below-knee prosthetic structures than traditional inverse dynamics methods. The model was also applied to the intact side, and quantified mechanical work of the combined ankle-foot system. A one-way repeated measures ANOVA was performed to compare mechanical work profiles across visits, with Fisher's LSD for post hoc testing ($\alpha < 0.05$).

RESULTS AND DISCUSSION

During the adaptation period, there was a statistically significant increase in total prosthesis side ($p = 0.041$) and intact side ($p = 0.036$) positive work (Figure 1). The largest increase seen in positive work was during the pushoff phase in gait (Figure 2). After 3 weeks, prosthesis and intact side positive work increased by 6.1% and 5.7% compared to initial values. No significant changes were found in negative work for prosthetic ($p = 0.155$) or intact side ($p = 0.202$).

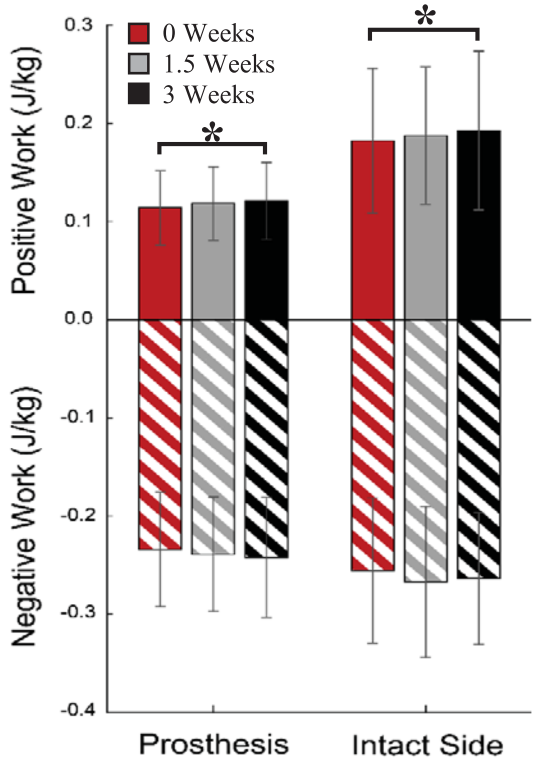

Figure 1: Positive and negative work done by prosthesis and intact side ankle-foot structures across visits (N = 22, mean ± stdev) (* denotes significant pairwise comparisons).

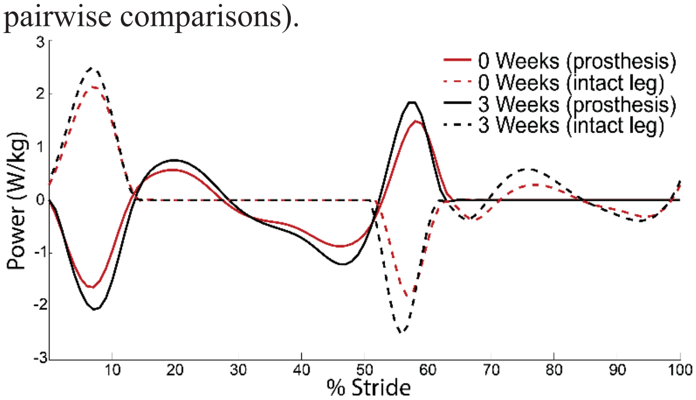

Figure 2: Prosthesis and intact side ankle-foot powers from a representative subject.

The increase seen in positive prosthesis work could reflect increased usage after adaptation, which would be desirable to reduce reliance on intact limbs for locomotion. However, there was no corresponding decrease in intact side positive power. There was also a 4.1% increase ($p = 0.038$) in group mean self-selected speed from initial to final visit, which may account for some of the increase seen in positive work. These results confirm some of our hypotheses but not others, meaning adaptation to a prosthesis may be more complex than previously thought. However, objectively quantifying prosthesis and intact side power may be valuable in tracking a patient's progress over time, or to view how well a patient is responding to a new prosthetic component. We are currently analyzing changes in mechanical work at other intact joints following adaptation.

CONCLUSIONS

Prosthesis and intact side positive work increase over a period of adaptation to a new prosthesis. Analyzing work done by an individual's prosthesis may be desirable for tracking a patient's physical rehabilitation and adaptation to a prosthesis over time. Future work will analyze how prosthetic mechanical work profiles relate to more traditional clinical measures.

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INFLUENCE OF EPOCHS LENGTH ON SCALE INVARIANT PROPERTIES OF DAILY MOTOR ACTIVITY

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INTRODUCTION

Human daily motor activity (DMA) is characterized by the presence of complex temporal fluctuations presenting scale invariance [1], e.g. the properties of fluctuations remains similar over a wide range of time scales, from minutes to hours. Scale invariance of DMA is estimated from time series composed of consecutive bouts of activity recorded per-epoch from an activity monitor [1,2]. The epochs length can vary from a few seconds to several minutes. However, it is critical to assess the influence of the epochs lengths on the scale invariant properties of DMA. Increasing epochs length is equivalent to averaging consecutive data points, and consequently losing some crucial information about DMA dynamics. On the other hand, very short bouts of activity are likely to provide a lot of 'zero' values and thus not be relevant. In this study we compared epochs length of 15 and 60 seconds, similar to what has been used in previous studies [1,2].

METHODS

At this time, five healthy young adults were recruited. Future data collection will include individuals with Parkinson's disease as well as age-matched control subjects.

Participants were instructed to wear the activity monitor on their non-dominant wrist for seven consecutive days. The activity monitor was the Actigraph GT9X [3], composed of two accelerometers, a gyroscope and a magnetometer. Accelerometer data were sampled at 100 Hz, and the Vector Magnitude (VM) was extracted for epochs of 15 seconds and 60 seconds. VM refers to the magnitude of the resulting vector that forms when combining the sampled acceleration from all three axes on the device, and is defined as:

VM=$\sqrt{(Axis\ 1)^2+(Axis\ 2)^2+(Axis\ 3)^2}$

We further analyzed the scale invariant properties of the VM time series from 9:00 am to 9:00 pm every day, corresponding to the 'active' period.

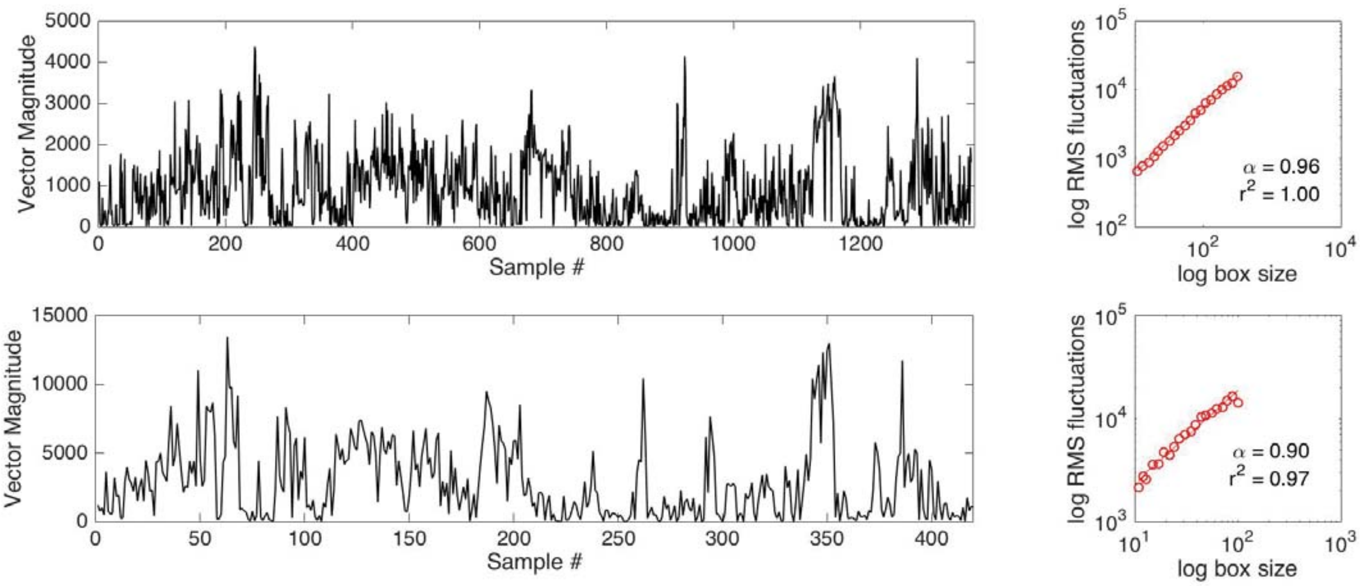

Figure 1: Representative example of the 'active' period of a VM time series (left) and corresponding DFA plot (right), for epochs length of 15 sec (upper panel) and 60 sec (lower panel). Note that the lower panel contains about four times less data points than the upper panel.

Detrended fluctuation analysis (DFA) was used estimate scale invariance of VM time series [4]. Briefly, the DFA provides an estimation of the size of fluctuations F(*n*) for each window of observation of size *n*. The slope of F(*n*) as a function of *n* in log-log coordinates corresponds to the scaling exponent α (Figure 1, right panels). We calculated α from individual daily VM, for epochs lengths of 15 sec (α_{15}) and 60 sec (α_{60}).

We calculated the Pearson's coefficient of correlation between all α_{15} and all $_{\alpha 60}$ to estimate the dependence between these two variables. Cronbach alpha from intra-class correlations (ICC) was calculated to determine how similar individuals α_{15} were to their corresponding α_{60}. We did not perform any statistical analysis to compare group means due to the small sample size (N=5).

RESULTS AND DISCUSSION

The Pearson's coefficient of correlation between α_{15} and α_{60} was r=0.890 ($p<0.001$; $r^2=0.792$). The Cronbach alpha value from the ICC comparison of the α_{15} and the α_{60} was $\alpha_{ICC}=0.847$. The average α_{15} and α_{60} were respectively 0.94 (SD=0.09) and 0.94 (SD=0.10). The distribution of individual daily α_{15} and α_{60} is reported in Figure 2.

The scale invariant properties of VM time series seems to be very similar when computed from epochs length of 15 sec or 60 sec. In particular, the averaged values are identical, and the Cronbach alpha values from the ICC reveals a high degree of similarity between α_{15} and α_{60} for individuals. However, the higher dispersion of α_{60} for individuals (Figure 2) suggests that using epochs length of 15 sec would provide more robust results.

CONCLUSIONS

The estimation of scale invariant properties of a given time series is dependent on the time series lengths. Consequently, using shorter epochs length provides more data point and potentially a better estimation of scale invariant properties of DMA.

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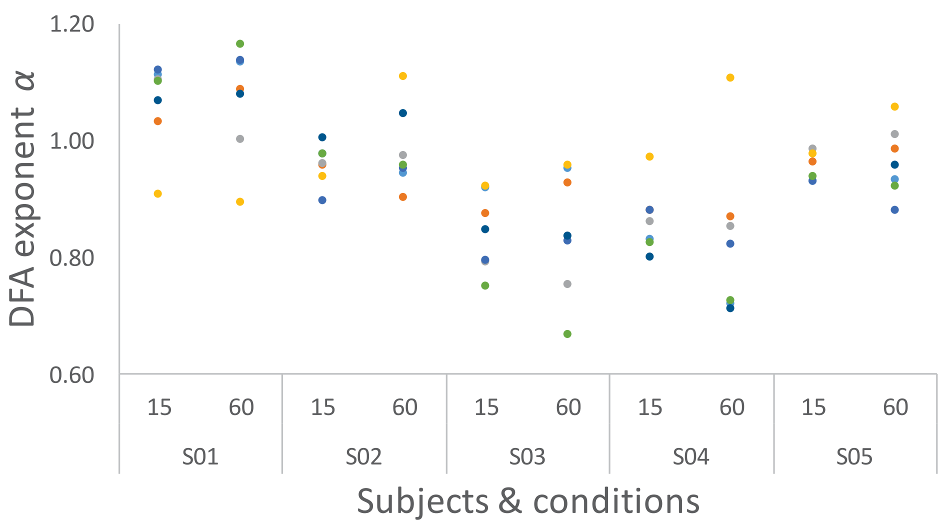

Figure 2: Distribution of individual α_{15} and α_{60}. Each colored dot represents the DFA exponent from the 'active' period of VM time series.

METABOLIC COST OF TRANSPORT AND FRACTAL VARIATIONS DURING HUMAN WALKING

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INTRODUCTION

A common feature of nature is the geometric fractal pattern: a shape that has the same form at large and small scales (think of crystals or snowflakes). Interestingly, this same phenomenon is observed in biological time series [1]. For example, human heart rate has fractal variability (the pattern of heartbeats is similar at large and small time scales). Indeed, it seems that fractal patterns are a hallmark of biological systems, as they are observed at the microscopic level (cellular organization and respiration) as well as at the gross level (breathing rate and stride frequency) [2]. Despite the ubiquity of these fractal variations, their function remains a mystery.

Clues have been gained, however, in studying how fractal stride frequencies are different in different populations. Changes in biological variability from fractal to random have been linked to decreased health [4] and/or expertise [5]. Another important marker of health is the metabolic cost of transport, or how much physiological energy is consumed to walk a certain distance [3]. Increased metabolic cost of transport is indicative of decreased energetic efficiency of the system. Thus, the aim of this study is to determine if a relationship exists between fractal variations in stride frequency and the metabolic cost of transport, and to determine the nature of this potential relationship.

METHODS

The participant (male, 26 years old) walked on a treadmill at 5 speeds, ranging from 0.75 – 1.75 m·s^{-1}. Each speed condition lasted 15 minutes, and the order of conditions was randomized. After the end of the final trial, preferred walking speed was experimentally determined. Kinematic data were collected using an 8-camera system (Vicon; Motek Medical; 100 Hz), and a 6-degrees-of-freedom marker-set [6]. Gait events were determined using foot velocities with respect to the pelvis [7].

For each walking speed condition, detrended fluctuation analysis was used to calculate the scaling exponent (a measure of persistence) of two time series: 1) stride length and 2) stride time. Values close to 1 indicate fractal behavior, with decreasing values denoting more random behavior. Left- and right-limb data showed similar trends and thus only the right-limb data are reported here. Metabolic cost of transport (MCOT) was calculated from inspiration/expiration rate of O_2/CO_2, from a gas exchange monitoring system (Kb^4, Cosmed). The metabolic rate of quiet standing was subtracted from trial data, which were then used to calculate net metabolic power (W·kg^{-1}) [8] and divided by speed to determine metabolic cost of transport (J·kg^{-1}·m^{-1}).

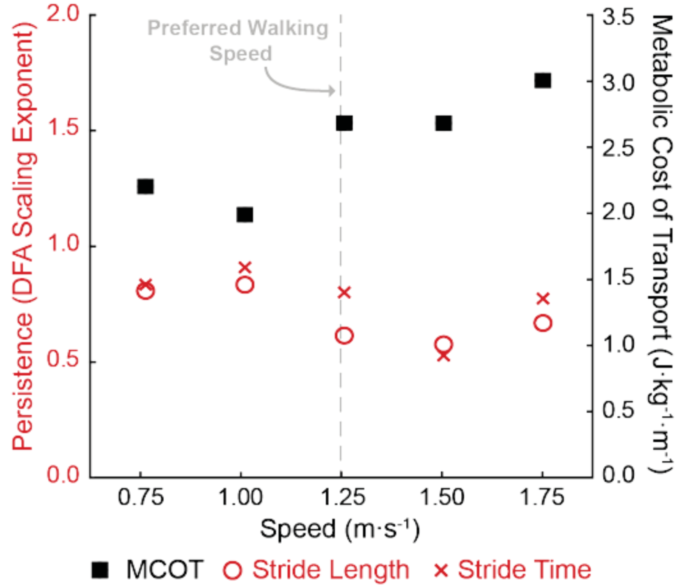

Figure 1: Metabolic cost of transport (MCOT, black) was lowest at 1.00 m·s^{-1} and the persistence of stride length and stride time (red) was highest at 1.00 m·s^{-1}.

RESULTS AND DISCUSSION

Metabolic cost of transport was lowest at 1.00 m·s^{-1} and persistence in stride length and time were highest at this same speed (Fig. 1). This preliminary, single-subject data suggests that metabolic cost and persistence of stride-to-stride fluctuations may be optimized at similar speeds, indicating a possible link between the two. This relationship will be further explored as we refine this study and continue with additional participants.

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Gait Dynamics are Constrained When Comparing Fixed Speed to Self-Paced Treadmill Gait

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INTRODUCTION

Instrumented treadmills are an important tool for gait analysis laboratories and research aiding rehabilitation. Several studies have shown that kinematic and kinetic profiles of treadmill gait are similar to that of over ground gait[1]. However, recent work has revealed that an individual's inherent gait dynamics might be altered[1,2] when on a treadmill due to the constraint of a fixed speed, subsequently requiring modification of one's behavior to maintain gait at this speed. This constraint leads to an adaptation in gait behavior that does not resemble over ground gait. This constraint becomes more prevalent in pathological populations or when subjects are given an additional task to perform when walking on a treadmill[2,3]. Fixed-speed treadmill great has been shown to limit joint range of motion about the ankle, knee, and hip and to increase cortical activity in the brain when compared to over ground[1-3].

Therefore, a treadmill that relieves the constraint of a fixed speed by adjusting to the user's behavior may be more transferrable to real-world situations while still utilizing the benefits of a treadmill. Thus, the purpose of this study is to investigate gait kinematics when comparing a self-paced treadmill to a fixed-speed treadmill. We hypothesize that the gait dynamics of healthy young adults walking on a self-paced treadmill will be significantly different than when walking on a fixed-speed treadmill.

METHODS

The self-paced treadmill algorithm was developed via custom scripts in D-flow (Motek Medical) utilizing kinematics from reflective markers placed at anatomical locations on the subject's hips, legs, and feet. The positions of these markers were recorded by an 8 camera motion analysis system (100 Hz; Vicon, Oxford, United Kingdom). The algorithm estimates the desired velocity of the individual based on velocity during foot swing. The estimated velocity is compared to the previous estimated velocity of the same foot to get the difference in estimated speeds across stride cycles allowing the algorithm to be more accurate across a wider range of gait behaviors. The difference is multiplied by a scaling factor based on the position of the individual on the treadmill and their kinematics about the trunk and foot swing. Using both of these criterions prevents the user from being bound by either position (a problem of other self-paced algorithms) or speed (a constraint of traditional treadmills). A max acceleration limiter is utilized in the algorithm and based off the user's behavior. The custom scripts sampled at 300Hz to provide input to the split-belt treadmill (Bertec Corp., Columbus, OH) to minimize further accelerations felt by the user.

Seven healthy young individuals consented to take part in this study to compare 2 different gait modalities: fixed-speed treadmill and self-paced treadmill. Each modality was a condition which included a 5 minute warm-up and 1 15 minute gait trial. The 5 minute warm up for fixed speed involved finding the subject's preferred speed. Conditions were randomized and subjects were not informed before each treadmill trial whether they were in self-paced or fixed speed mode.

RESULTS AND DISCUSSION

The independent variable is mode of gait. In order to assess the effects on gait dynamics, fractal dynamics (using detrended fluctuation analysis) and Sample Entropy were used to analyze step width and stride time, speed, and length time series. Seven hundred and seventy-five strides were used for analysis. Paired t-tests were used to compare the gait modality effect on each dependent variable.

Significant differences were found between gait modalities for stride time on the right leg (Sample Entropy only, p<0.05, Table 1). Stride Speed was significantly different as measured by detrended fluctuation analysis (p<0.05, Table 1).

CONCLUSIONS

Gait dynamics are limited on a fixed-speed treadmill compared to a self-paced treadmill in this sample of subjects. More subjects are needed to determine the effect of a self-paced treadmill on gait patterns.

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Table 1: Tables may extend across both columns, and those should be included at the bottom of the abstract.

<table>
<tr><td>Gait Mode</td><td></td><td colspan="2">Stride Time</td><td colspan="2">Stride Speed</td><td colspan="2">Stride Length</td><td colspan="2">Step Width</td></tr>
<tr><td></td><td>leg</td><td>Sample Entropy</td><td>Alpha</td><td>Sample Entropy</td><td>Alpha</td><td>Sample Entropy</td><td>Alpha</td><td>Sample Entropy</td><td>Alpha</td></tr>
<tr><td rowspan="2">Self-Paced Treadmill</td><td>R</td><td>1.74*</td><td>0.90</td><td>1.71</td><td>0.94*</td><td>1.77</td><td>0.9</td><td rowspan="2">1.75</td><td rowspan="2">0.70</td></tr>
<tr><td>L</td><td>1.70</td><td>0.89</td><td>1.69</td><td>0.93*</td><td>1.76</td><td>0.9</td></tr>
<tr><td rowspan="2">Fixed-Speed Treadmill</td><td>R</td><td>1.51</td><td>0.76</td><td>1.98</td><td>0.45</td><td>2.08</td><td>0.74</td><td rowspan="2">1.79</td><td rowspan="2">0.70</td></tr>
<tr><td>L</td><td>1.51</td><td>0.77</td><td>2.01</td><td>0.45</td><td>2.11</td><td>0.74</td></tr>
</table>

Key: Significant differences (p < 0.05) from Fixed-Speed Treadmill gait are indicated by *.

EVIDENCE OF MOTOR CONTROL STRATEGIES IN DYNAMICAL SYSTEMS THEORY: A CASE STUDY IN COLLEGIATE SOFTBALL PITCHERS

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INTRODUCTION

The dynamical systems perspective (DSP) suggests that human movement contains inherently varying patterns, even when the individual intends to repeat the same movement [3]. Rhythmic movements like walking/running and trained discreet movements like a golf swing or racquet swing have subtle variations in the degrees of movement.

The DSP in regard to human performance suggests that those with a wide range of movement variability have increased capacity to adapt *during* a movement than those who have a smaller range of movement variability. [2]. Consistent performance outcomes that repeatedly occur with variable patterns of movement suggest that motor control strategies are in place to adapt to these variations. [1] Therefore, one can surmise that in consistent performance, these adaptations *during* movement could include temporal, spatial or force distribution changes. To investigate this idea, we examined the pelvis and torso kinematics of the windmill pitch.

METHODS

Four female division-1 collegiate softball pitchers (age: 20.8 ± 1.0 years; height: 168.5 ± 5.1 cm; body mass: 92.2 ± 21.5 kg) participated in this study. Fastball pitches were analyzed under two conditions: pre-fatigue (pre) and post-fatigue (post). Participants performed 20 pitches in the pre-condition and 15 pitches in the post- condition Full-body kinematic data were recorded at 250 Hz (Qualisys, Göteborg, Sweden). Following completion of the pre- trials, the participant pitched 20 fast-balls in a row as quick as possible, rested for 30 seconds, then pitched 20 more rapid-fire fast-balls. Immediately following the second set of 20 fatiguing pitches, pitches were recorded for the post- condition.

Transverse plane segment angles and rotational distance for the pelvis and torso were calculated and time stamped using Visual 3D software (C-Motion, Germantown, Maryland). All pitches were analyzed from push-off, defined as the moment of maximum anterior propulsive force, to release, defined as the frame where the ball is no longer in visual contact with the hand.

Raw data consisted of variables of the pelvis and torso: **Angular Positions, Rotation Distance** (range), **Time to complete the rotation**, and **Pitch Velocity.** Additional variables were created:

Angular Position Correlation: Fisher's Z test cross-correlations from the raw angular positions were calculated to determine the similarity between the pelvis and torso angular positions.
Rotation Distance Pelvis and Torso: The rotation distances of pelvis and torso were calculated separately by subtracting the raw values of from the minimum rotation to maximum rotation of each.
Rotation Distance Ratio: The pelvis to torso ratio was calculated by dividing pelvis distance raw values by torso distance raw values.
Rotation Distance Correlation: This Spearman's correlation compared rotational distances of the pelvis and torso. A Fishers Z test was used to compare pre and post within-subject correlations.
Rotation Time Difference: The time difference of pelvis and torso rotation was calculated as the

difference in elapsed time in seconds from the minimum rotation to maximum rotation of each. **Pitch Velocity:** Pitch speed was calculated with a speed gun and measured in miles per hour.

RESULTS AND DISCUSSION

Dependent t-tests were used identify any significant differences across pre and post conditions both between and within subjects with alpha level $p < 0.05$. Significant differences were found in within-subjects comparisons in multiple measures, but notably not in all the same measures.

Within-Subject Measures:

Subject 1 showed differences in Rotation Distance Ratio and Rotation Distance Correlation ($p = 0.008$ and 0.004 respectively), but not in Angular Position Correlation, or Rotation Time. This result suggests her movement variability is more spatial than temporal.

Subject 2 had the highest Angular Position variability in pre and post measures. The within-subject comparisons show differences in her Rotational Distance Ratio between pelvis and torso *($p =0.04$)*, but *not* Rotation time, Rotation Distance Correlation, nor Angular correlation, ($p > .05$). This result suggests she varied the angular position while maintaining the temporal and force distribution of the pelvis and hips during the pitch.

Subject 3 appeared to have the least variability. Further, none of her pre and post measures were significantly different, ($p > .05$).

Subject 4 shows differences in Angular Position correlations, ($p = 0.02$), but not in Rotation Time Difference, Rotation Distance Ratio nor Rotational Distance Correlation. This result suggests her movement variability is more spatial than temporal.

Other Measures:

The average pitch velocity for pre and post conditions did not differ significantly *($p = .19$)*. Subject 2 recorded the highest average pitch speed (64.85 mph), and the only significant difference in pre vs. post conditions (1.18 mph slower, $p = .001$.) *Within* subject comparisons showed no significant loss of velocity for 3 of the 4 subjects *($p > .05$)*. Additional results show no differences in across-condition comparisons in any of the other movement measures, $p > .05$.

CONCLUSIONS

Motor control strategies have been suggested to be used to maintain performance by counteracting inconsistency under inherently variable movement patterns.[1] Using pitch velocity as a measure of consistency, each subject maintained consistent performance through pre and post conditions except one. The overall movement variability across conditions did not differ significantly. It is conceivable that the within-subjects differences in separate components were evidence of spatial and force distribution motor control strategies (but not temporal strategies) to maintain consistency.

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Figure 1

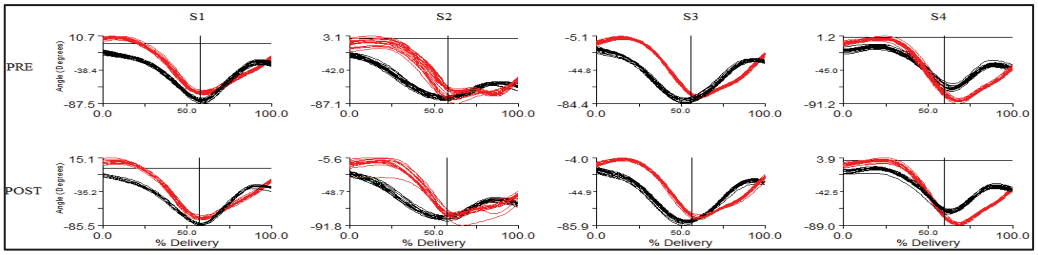

Figure 1. Shows pre and post -fatigue angular positions of the pelvis (top group of lines) and torso (bottom group of lines) of the four pitchers.

Differences in Center of Pressure Measures Between Arithmetic and Auditory Single-Limb Dual Tasks

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INTRODUCTION

Dual-task paradigms have been used to stimulate cortical involvement in sensorimotor control and postural balance in humans [1]. These paradigms are frequently utilized to perturb a sensory system, or systems, allowing insight into one's ability to negotiate cognitive loads while performing a motor task [2]. Different cognitive loads may stimulate different areas of the brain [4]. Calculative tasks are performed in the parietal lobe [4] while sounds are processed in the temporal lobe [8]. While each of these are processed in separate areas, their interaction with motor responses remains unclear. Therefore, the goal of this study was to investigate two different types of cognitive perturbations, an arithmetic task and an auditory task, and how they affect spatial awareness in a healthy population.

METHODS

Fourteen, 19-35 year old recreationally active healthy subjects (male=6, female=11, age 22.6 ± 2.8, height (cm) 172.9 ± 11.1, mass (kg) 79.6 ± 13.9) were recruited to participate in this study. Participants were considered recreationally active under the moderate category of the ACSM guidelines completing at least 90 minutes of physical activity per week. Participants were excluded if they have had a history of concussions or a history of lower extremity surgery or fracture.

Subjects participated in two separate days of testing. On the first day, they were instructed to stand on a single-limb (SLT) with hands on their hips for a total of 60s on a force-plate (Neurocom Balance Master System 8.4 Equitest; Neurocom International Clackamas, OR; 100Hz). Five trials were performed on each leg. A minimum of one week later, participants performed the same SLT while completing an auditory or serial-subtraction task separately. The auditory task, dichotic listening test (DLT), consisted of 6 different consonants (Ba, Da, Ka, Pa, Ga, Ta), which were delivered to the subject via headphones. Consonant clusters are delivered to the right and left ear simultaneously. The subject repeated what consonant he or she hears clearest for a set of 36 total attempts in 60 seconds. This condition was repeated 8 times for each leg. The serial subtraction task (SST) prompted the subject to start from 100 and count backwards by 7s as quickly and accurately while saying their answer out loud. This task was repeated 5 times for each leg.

Range, root-mean-square (RMS) and velocity (COPv) of the center of pressure was calculated for both anterior-posterior (AP) and medial-lateral (ML) directions for each of the trials and averaged. A multivariate analysis of variance (MANOVA) was used to identify differences among SLT, DLT, and SST paradigms. If significant results were found pair-wise comparisons were completed to determine where specific differences existed. Significance was set to $p<.05$ for all tests.

RESULTS AND DISCUSSION

Descriptive statistics for each of the center of pressure dependent variables by condition are located in Table 1. A significant main effect for condition was found (F=2.21, p=.03). Pairwise-comparisons found differences in the AP-range, AP-COPv, ML-Range, and ML-COPv. Specifically, the SST had higher values in AP-Range compared to DTL (p=.04), DTL had higher values of AP-COPv compared to both SLT (p=.01) and SST (p=.03), the SST had greater ML-Range compared to both SLT (p=.02) and DTL (p=.01), and the SST demonstrated greater ML-COPv compared to the SLT (p=.01) and DTL (p=.01). It appears the SST demonstrating the worst COP values across the three conditions. Velocity in the AP, the data indicates that there is a significant difference between the arithmetic task and the auditory task ($p < .05$). Therefore, postural control was compromised more in the arithmetic dual task.

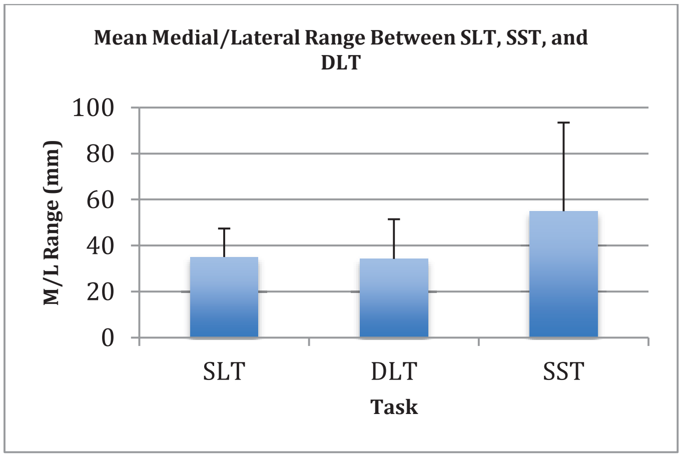

Figure 1: This figure illuminates the differences in the mean range in the M/L direction between the three tasks.

Results show that there is increased deficit of stability during the SST, more so than the DLT. This could be attributed to the fact that serial subtraction could command more of a cognitive load as compared to the dichotic listening test during single legged balance [6]. Previous studies have shown the arithmetic task, conducted simultaneously with postural balance, does in fact disturb posture by competing for cognitive resources [6]. The area of the brain that is known for processing an arithmetic task is also the same area that is known for processing spatial cognition [1], the area is identified as the angular gyrus [5]. For the DTL, there is a cascade of development this information must go through in order for effective brain processing. Auditory information is transported from the cochlea hairs in the ear, to the primary auditory cortex, and finally to the thalamus to integrate all sensory systems to develop response [7]. This neuronal transportation of the auditory task could cause the signal to become attenuated, therefore not applying as much of a cognitive load as compared to the arithmetic test.

CONCLUSIONS

Tasks involving arithmetic have been shown to precipitate a larger disturbance in motor disturbance than auditory tasks. Due to the close proximity of the two processes, it is suggested postural stability and calculative tasks may compete for similar resources. This may have further implications on activities of daily living and more complex tasks during recreational activities. Further research is necessary to understand how these differences may be compounded during more complicated tasks.

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Table 1: Descriptive Statistics of CoP in the M/L direction from each task of both right and left leg.

	Anterior-Posterior (mm)			**Medial-Lateral (mm)**		
	Range	**RMS**	**Velocity**	**Range**	**RMS**	**Velocity**
Single-Task	42.0±12.1	6.9 ± 1.6	.47 ± .07	35.0 ± 12.4	5.6 ±1.5	-.019 ± .086
Dichotic Listening	40.9±11.8	6.7 ± 1.3	.51 ± .11	34.0 ± 17.2	5.3 ± 1.5	-.008 ± .080
Serial Subtraction	53.0±30.1	8.1 ± 3.8	.55 ± .07	54.9 ± .38.6	7.3 ± 5.0	-.34 ± .42

IMPACT OF ADIPOSITY ON PHYSICAL ACTIVITY LEVELS OF YOUNG INFANTS

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INTRODUCTION

Studies suggest that infant adiposity may delay the development of motor skills such as sitting.[1-3] However, the role of physical activity (PA) in the development of motor skills during the first year of life has been understudied and little is known about the amount of PA needed for normal growth and development in infants[4,5]

Therefore, the purpose of this study was to examine the impact of adiposity as measured by skinfold thickness (SFT) on PA of typically developing infants at three months of age (visit 1), onset of sitting (visit 2), and one month post (visit 3).

METHODS

Twenty-two infants (n=8 high SFT, n=14 lower SFT) participated in a pilot study examining the relationship between infant PA and postural control in normal weight and overweight infants. High SFT was classified as having a subscapular and triceps measurement in the 85th percentile or above according to the WHO age and sex-specific standards.[6]

Infant PA was measured using Actigraph Link accelerometers on the left wrist and ankle for four consecutive days at each of the three time points. The PA outcome variable was the average total vector magnitude counts (TVMC) from ankle and wrist accelerometer. Data were analyzed using a repeated analysis of variance and a three way ANOVA to examine the effect of sex, gender, and SFT class (i.e., high vs lower) on TVMC.

RESULTS & DISCUSSION

There were no significant differences in the onset of sitting between the two groups. A repeated measures ANOVA with a Greehouse-Geisser correction determined there were no statistically significant differences in mean TVMC between time points $F(1.834, 29.348)=1.111$, $p < 0.338$). Post-hoc tests using the Bonferroni correction revealed that infant's PA in the second visit was the higher 5698.91 ± 1661.03 TVMC than the first visit 5113.91 ± 1661.28 TVMC, p=1.00 and the third visit 5054.31 ± 1918.23 TVMC, p=0.89. Additional three-way ANOVA revealed no significant main effects and interaction effects on sex × SFT × gender).

CONCLUSION

Although it was not significant there was a decrease in wrist TVMC for overweight infants from visit 2 to 3. More research is needed to determine if a significant difference develops during the acquisition of additional motor skills.

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ATTENTIONAL CAPACITIES ARE RELATED TO NONLINEAR MEASURES IN THOSE WITH CHRONIC ANKLE INSTABILITY BUT NOT THOSE WITHOUT

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INTRODUCTION

Ankle sprains are some of the most frequent athletic injuries. After a sprain, chronic ankle instability (CAI) often develops, and is characterized by a persistent recurrence of ankle injury and decreased function. The cause of CAI is currently unknown, though recent research suggests that the nature of CAI is not just musculoskeletal, but neuromuscular as well [1]; attention may play a role, as those with CAI may have difficulty when faced with cognitive loads [2]. Attention is limited, and used by cognitive and motor processes [3] – therefore, attentional capacities may affect performance in those with CAI.

Examining movement variability may provide greater insight into the system and may help elucidate possible alterations in neuromuscular control in those with CAI. Variability is a series of complex, fluctuating patterns, previously thought to be an artifact of noisy data [4]. Recent advances in technology and nonlinear analyses have shown that variability is not, in fact, unwanted noise, but a desirable healthy characteristic of complex systems [4]. Disturbances in system complexity are associated with impaired states [4], and so it may prove beneficial to examine variability to gain insight into CAI. Thus, this study's purpose was to assess variability in participants with and without CAI, during a single-limb stance.

METHODS

This study recruited 40 subjects (17 males, 22.5±2.5 years, 171.9±10.2 cm, 72.6±13.1 kg). Groups were assigned according to prior ankle injury/function, and score on the Cumberland Ankle Instability Tool (CAIT). Controls (CON) had no history of sprains, no signs/symptoms of ankle dysfunction, and a CAIT ≥28. Copers (COP) had one or more prior sprains, no signs/symptoms of dysfunction, and a CAIT ≥28. Those with CAI had a history of ankle sprains, signs/symptoms of CAI, and a CAIT ≤24. Subjects must have been active for at least 90 minutes per week, and were excluded for any prior concussions or lower-limb fractures/surgeries, or any current musculoskeletal disorders.

While on a force platform (Neurocom, Balance Master System 8.4, Clackamas, OR, USA; 100 Hz), subjects were asked to quietly stand one-legged, alternating sides, for 5 trials each limb. After the balance trials, subjects were asked to complete the Central Nervous Systems Vital Signs (CNSVS). The CNSVS is a battery of valid and reliable computer-based neurocognitive tests which assess various functions, including attention. Attentional variables from the CNSVS included simple and complex attention (SA and CA); higher scores indicated better cognitive function.

Measures calculated from the force platform's center of pressure (CP) data were: α-values of detrended fluctuation analyses (DFAs); sample entropies (SEs); and r-squared values (r^2) – each calculated in both the anteroposterior (AP) and mediolateral (ML) planes.

An ANOVA assessed differences in attention and CP variables between CAIT groups. Data was then evaluated using correlational analyses between all CP variables and attention, with separate analyses for each CAIT group. Statistical significance was p=.05.

RESULTS AND DISCUSSION

The results indicated no differences between groups for any CP or attentional measures. There were, however, differences in correlations of simple attention vs α-values and sample entropies between each of the groups (Table 1). In the CON group, no correlations existed between any of the attentional or CP variables. In the COP and CAI groups, however, moderate to strong correlations existed. The COP group showed moderate negative correlations between complex and simple attention vs α-values, in both the AP/ML directions. The CAI group showed strong negative correlations between simple attention and α-values, with the addition of a strong positive correlation between simple attention and sample entropy. (Fig. 1) Together, these correlations suggest less complex and more periodic motion.

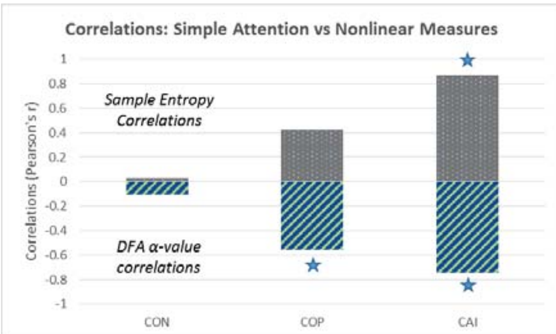

Figure 1: Correlations in simple attention vs α-values and sample entropy. Stars denote significance.

In this study, COP and CAI subjects with higher simple attention showed less complex CP sway. DFA analyses examine the chaotic nature of a system, giving insight into its complexity, and pattern of fluctuation. For α-values, a high negative correlation indicates a tendency toward less complex data as attention increases. Sample entropy is a measure of how likely a certain pattern is to repeat itself, and how predictable a set of data is. Lower sample entropies are characteristic of more random data. A positive correlation between simple attention and sample entropy implies that those with higher simple attention scores tend to have more repetitive motion. In our CAI group, there was a large negative correlation between simple attention and sample entropy; CAI subjects with higher simple attention exhibited more repetitive CP motion.

The lack of correlations in CON with moderate and strong correlations in COP and CAI may suggest different attentional demands for those with more or less ankle stability. Aside from the CON group, those with higher attentional scores also exhibited less complex, and more periodic sway of CP. It has been suggested that too little complexity or too much periodicity leaves a system less able to adapt or respond to perturbations [4]. Therefore, in the context of ankle stability, it would seem these findings support the notion that those with higher attention have a tendency towards being less able to respond to perturbations. This seems counterintuitive based on prior studies [2], and further investigation is required to better understand this phenomenon.

CONCLUSIONS

The findings of this study suggest that attention can be a large moderator in those with and without CAI, and that those with ankle instability may be dependent on attentional demands to maintain balance and stability. These findings may have an impact on rehabilitation protocols for those with different levels of attention. However, further research is necessary to elucidate this phenomenon.

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ACKNOWLEDGEMENTS

This study was partially funded by the Center of Research in Human Movement Variability Pilot Project Mechanism (NIH COBRE; P20 GM109090) and the Mid America Athletic Training Association.

Table 1: Correlations between CP measures and simple attention in CAIT groups. *$p<.05$, **$p<.01$, ***$p<.001$

		Antero-Posterior Direction			Medio-Lateral Direction		
	SA vs CA	DFA α-value	r^2	S. Entropy	DFA α-value	r^2	S. Entropy
CON	$r = 0.471$	$r = -0.105$	$r = 0.054$	$r = 0.027$	$r = -0.222$	$r = 0.101$	$r = 0.053$
COP	$r = 0.988$***	$r = -0.556$*	$r = -0.488$	$r = 0.426$	$r = -0.598$*	$r = -0.410$	$r = 0.427$
CAI	$r = 0.279$	$r = -0.744$**	$r = 0.061$	$r = 0.868$**	$r = -0.681$*	$r = -0.027$	$r = 0.815$**

DESIGN AND VALIDATION OF A COMPLEX TERRAIN GENERATING VARIABLE SURFACE TREADMILL

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INTRODUCTION

While modern treadmills have afforded many with the ability to change speed and inclination of the terrain surface [1], they lack the ability to simulate more real-life scenarios. The manipulation of obstacles and terrain is fundamental to understanding the intricacies of human movement [2]. This work involves the development and validation a Variable Surface Treadmill (VST) that allows for dynamic simulation of complex terrestrial and extraterrestrial terrains. We expect that this novel treadmill will allow us to investigate the basic principles governing sensorimotor functions in human locomotion, as well as develop novel interventions to retrain people with mobility-affecting disorders.

The implementation of a complex terrain generator such as The Variable Surface Treadmill will allow for exploration of sensorimotor dysfunctions that compromise natural walking. Common walking impairments like stamping gait, drifting off the intended path, abnormal step length, and widening the base of support may be targeted and recovery accelerated. To achieve this acceleration, an interactive sensorimotor training method is warranted during rehabilitation. The development of the VST can support this long-term goal, and due to its versatility, it may enable individualized locomotion intervention.

Whether it be persons with sensorimotor impairments, limb amputations, or stroke survivors, new methods intended to improve their conditions are monumental to continued progress. The VST will allow for exploration into how humans adapt to complex tangible terrains. During this effort, we will study how healthy adults maneuver over such complex terrains generated dynamically by the Variable Surface Treadmill. Current work is being done to ensure the ability to generate said terrain in both programmed and random conditions.

We hypothesize that results of planned future studies will indicate that individuals walking on a dynamically adaptive terrain (created by the VST) will show increased gait variability and increased metabolic cost. This anticipated result will be central to future interventions aimed to challenge the sensorimotor system to maximize rehabilitation outcomes.

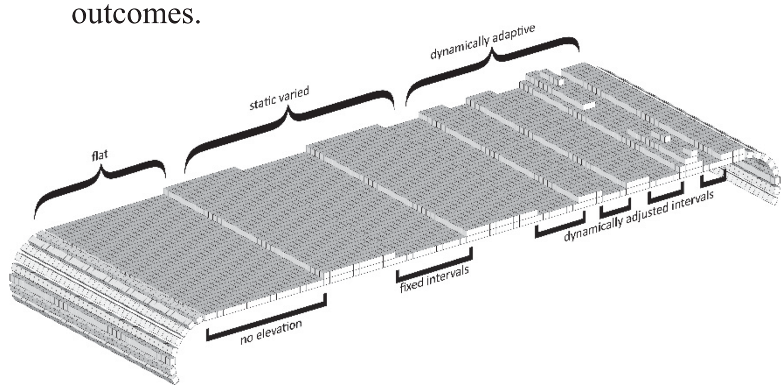

Figure 1: A comprehensive illustration of the Variable Surface Treadmill and the various research methods and future uses.

METHODS

We will complete design and development of the Variable Surface Treadmill that is comprised of hundreds of individually programmable, weight supporting actuators. The VST is intended to generate a dynamically adaptive terrain to further multiply the number of potential complex surface compositions in use by clinicians and researchers investigating rehabilitative or research-centric objectives. In order to test the ability to dynamically generate complex terrain in both hardware and software, we will test the VST's ability to randomly change the distances between obstacles while in use (Figure 1). For validation, we will measure the distribution of the obstacle-to-obstacle distances using a 3D motion capturing system to verify the hardware output.

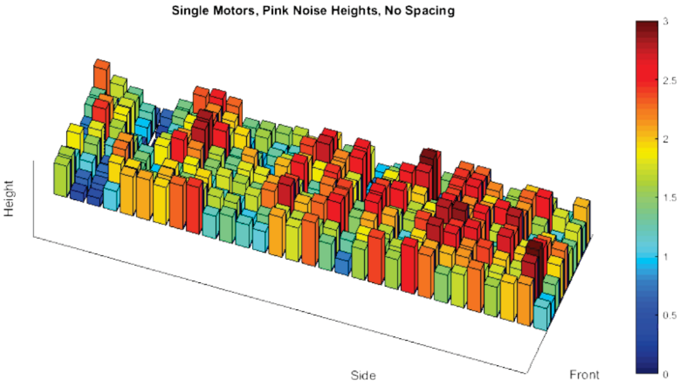

Figure 2: MATLAB generated user interface used for programming and selecting desired surface compositions.

RESULTS AND DISCUSSION

Upon validation of the VST's ability to generate such complex terrains, we plan to put it to use exploring the effects on healthy adult walking. Healthy adults will then walk on three different terrains: a flat terrain (i.e., a normal treadmill), a static obstacle terrain (i.e., obstacle-to-obstacle distances that remain fixed), and a dynamically adaptive terrain (i.e., obstacle-to-obstacle distances that change continuously).

The anticipated result will establish the potential use of dynamically adaptive terrain as a rehabilitative measure for persons with movement disorders. The VST could then be used in the International Space Station as an atrophy prevention technique. There are potential uses in neurorehabilitation and motor learning and development.

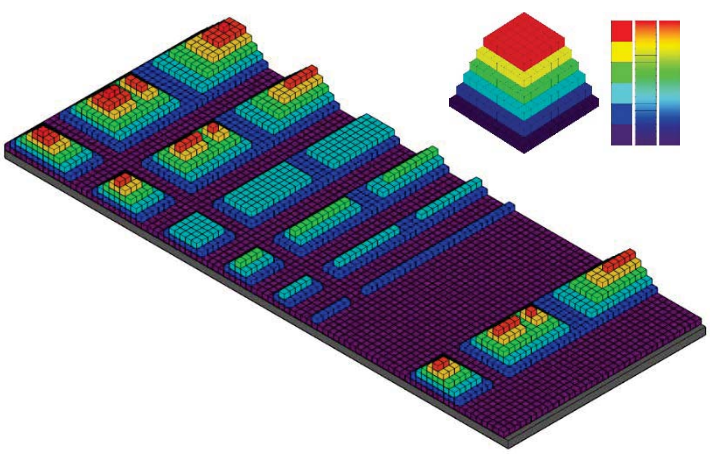

Figure 3: An illustration of the multi axis resolution capabilities of the Variable Surface Treadmill. With a high level of resolution, the surface composition can be finely tuned to deliver the exactly specified requirement.

ACKNOWLEDGEMENTS

This project is funded through NASA EPSCoR and supported by the NIH and the Center for Research in Human Movement Variability.

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THE EFFECTS OF TASK DIFFICULTY AND VISION DURING DUAL-MOTOR TASKING ON GAIT IN YOUNG AND OLDER HEALTHY ADULTS

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INTRODUCTION

In 2013 alone, 25,593 older adults (age 65 years and older) died as a result of injuries from a fall [2.] Falls have been linked to several different factors including: dementia, visual impairments, neurological and musculoskeletal disabilities, medications, decreased vision and balance, gait abnormalities, and trips [1]. A majority of falls in the older population occurs while walking [1], which has contributed to the study of gait variability. Gait variability is defined as the normal variations occurring from stride to stride across a time series [6]. The aging process contributes to a less consistent stepping pattern and more variable gait cycle, which can be used to predict falls as well as contribute to their occurrence [4].

The use of dual-task paradigms have begun to be incorporated into research protocols to study the amount of attention that is paid to two simultaneously performed tasks and how the performance of each of those tasks suffer. The secondary task in addition to walking can either be cognitive(counting backwards by seven's) or motor (carrying groceries) in nature. Dual-tasking will typically result in either a decrease in gait performance and/or a decrease in the performance of the second task.

Limited research has been done to investigate the effect of dual-motor tasks while walking in non-pathological populations. It has been suggested that adding a secondary task to walking increases the attentional demands of the system, allowing less attention to be devoted to walking alone. Older adults require more attention when walking than younger adults [1]. When another task is added on top of walking the attentional demand is even higher. As attentional demands intensify, the association between mobility performance and the role of executive function becomes stronger [5].

The purpose of this study is to investigate the effect of task difficulty and vision during dual-motor tasking on gait variability in younger and older healthy adults. We hypothesize that older adults will perform worse on increasing difficulty of the dual-motor tasks as well as rely more on their vision to maintain some level of performance.

METHODS

Fifteen younger adults (ages 19-35 years) participated in this study including 5 male (19-22 years) and 10 females (19-25 years). Participants were excluded if they had any comorbidities, disease, injury or surgery that would affect their walking ability.

The experiment consisted of two visits to the laboratory. Participants were first consented and asked to fill out demographic questionnaires. The participants then underwent screening tests including: The Digit span, Digit symbol, and Vocabulary from the Wechsler Adult Intelligence Scale-Revised to assess general cognitive functioning. The Frontal Assessment Battery was used to assess the central nervous system function. The Fullerton Advanced Balance scale and Sensory Organization test was used to assess balance. A lower extremity muscle strength assessment was completed on the ankle dorsiflexor and plantarflexors muscles bilaterally using an isokinetic dynamometer (Biodex 4.0, Biodex, Shirley, NY).

The second visit consisted of seven different experimental conditions. Subjects were asked to wear a tight-fitting suit and 33 reflective markers were be placed on the lower extremities in order to track the bodies movement through space as well as coordinate the treadmill. All participants were be asked to walk on a self-paced treadmill that used the reflective marker positions to adjust the speed of the treadmill to the walking speed of the participant. To ensure their safety and understanding of how the The first condition, baseline, was the same for every participant. The next four conditions were presented in randomized order (Table 1). The conditions used either a black or clear, round shaped tray to affect vision. Task difficulty was increased by placing four 1.5 oz filled water glasses on top of the tray. The final two conditions testing prioritization were also presented in randomized order. For all conditions, the participant was instructed to carry the tray out in front of them with two hands.

Condition	Description
C1	Baseline normal walking
C2	Carrying clear tray
C3	Carrying clear tray with filled water glasses
C4	Carrying black tray
C5	Carrying black tray with filled water glasses
C6	Prioritize walking
C7	Prioritize carrying the tray

Table 1. Description of the seven different experimental conditions. Subjects carried the tray out in front of them with two hands while walking.

RESULTS

No significant differences were found between conditions for the healthy young subjects. Two subjects were excluded from analysis because their data series were not long enough. Spatiotemporal variables were calculated for all conditions for the 13 subjects utilized for analysis. Sample entropy was then calculated on the step width data from these same subjects and conditions (Figure 1).

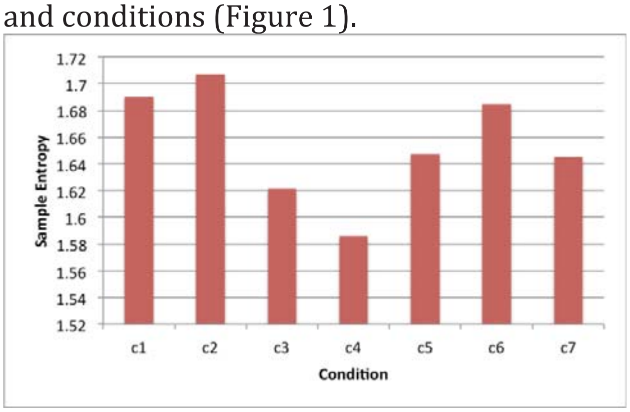

Figure 1. Average Sample Entropy values for all subjects across conditions.

treadmill worked, an adaptation/warm-up period of at least five minutes was completed prior to the experimental conditions.

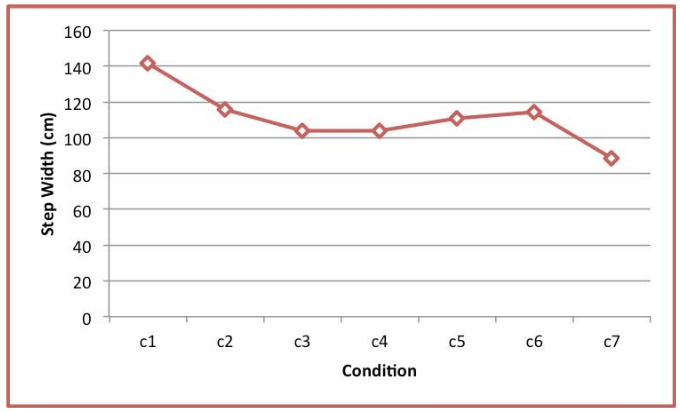

Figure 2. Representative subject of average step width values for the seven different conditions.

DISCUSSSION

Although no significant differences in spatiotemporal variables were found between conditions, it was interesting to see that step width decreased for most participants when the tray was added to walking, as seen in the representative subject. This is not what was expected, because typically a wider step width is adapted to provide more stability.

Further research is needed in order to compare these results to healthy older adults in order to make comparisons between the two groups. Further analysis will also be done in order to make better conclusions about the data from each independent population being studied as well.

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Infants Show a Preference for Social Images in the First Year of Life

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The increasing occurrence of autism spectrum disorders (ASD) creates a crucial need for clinicians to identify ASD-related deficits as early as possible so that children may receive access to intervention services as early as possible. Currently, the typical age of diagnosis for ASD is around three years of age. However, signs of atypical behavior have been documented retrospectively by parents as occurring earlier than this three-year mark. It has been suggested that gaze behavior could be a useful marker of developmental disruption in children with ASD. A very simple method, known as the preference looking paradigm, has been utilized successfully in toddlers as young as 14 months for the identification of ASD, but it has not been tested in infants. Therefore, the purpose of this study was to investigate the gaze behavior in typically developing infants and infants at-risk for autism at three, six, nine, and 12 months of age. Identifying early preferential looking differences in infants may allow for an increased understanding of the underlying visual processes, the development of an early detection paradigm for autism, and the advancement of foundational knowledge from which treatments for autism may be developed. Ten typically developing infants and one at-risk infant were examined in this study longitudinally. An infant was defined as at-risk if he/she had a sibling diagnosed with autism. Each infant was shown a preferential looking paradigm with social images shown on one side and geometric images on the other side. Results showed that both typically developing infants and the infant at-risk showed a preference for social images and that preference increased with age. Even though these preliminary results do not confirm our initial hypothesis, it is possible that even though infants at-risk do prefer social images, they do not perceive the social information from those images as do typically developing infants. Further research in this area is needed to verify these findings.

EFFECTS OF AUDITORY STIMULUS NOISE LEVELS ON THE LOCOMOTOR-RESPIRATORY COUPLING

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INTRODUCTION

Breathing and walking are physiological processes, which are naturally coupled in humans [1]. This is referred to as locomotor-respiratory coupling. An auditory stimulus has been used to pace the physiological systems, in which the effect of pacing has been an increase in coupling strength [2] and an increase in the degree of coupling [3]. The stimulus used in these previous studies has been a metronome, which is an invariant noise signal. The absence of variability may negatively affect the physiological systems, as variability is a natural characteristic in healthy systems [4].

The negative effect of pacing one of the physiological systems to an invariant noise stimulus (i.e. metronome) may, due to the coupling between systems, also negatively affect the secondary system. This study will compare the effects of three types of stimuli (white noise, pink noise, metronome) on the locomotor-respiratory coupling. The purpose is two-fold: To investigate 1) how one system is affected by pacing with different auditory stimuli; and 2) the effect on the secondary (coupled) system.

METHODS

A total of 10 healthy, young adults (Age: 23.1 ± 2.59 years; Height: 175.05 ± 7.93 cm; Weight: 75.52 ± 9.32) participated in the IRB approved study. The research project consisted of seven trials. The first condition served as the baseline condition, with the order of the remaining conditions randomized.

The participants walked on a self-paced treadmill at a comfortable speed for 16 minutes. The last 15 minutes were used in the data analysis, as the first minute allowed the participant to find a comfortable walking speed. From the results of the first condition (baseline), auditory stimuli were created to match the participant's natural breathing and walking frequencies.

During the final six conditions of the visit, an auditory stimulus was played while the participant walked on the treadmill. The participant was instructed to pace his/her breathing or walking to the beat, depending on the particular condition. For three of the final six conditions, the auditory stimulus played a beat similar to the participant's walking frequency. For the second set of three, the beat of the auditory stimulus was similar to the participant's breathing frequency.

Step time (time between one heel strike and the subsequent heel strike of the contralateral leg) and breath time (time between breath in and breath out and vice versa) were recorded. Using motion capture data, heel strikes were evented at the max forward placement of the foot. Using the distance between the chest and back markers from motion capture data, beginning of inspiration and expiration were evented at the minimum and maximum distance, respectively. In order to examine the change (or lack thereof) in the walking and breathing structures due to the three different auditory stimuli, two repeated measures ANOVAs (baseline and 3 noise signals) were used. The Bonferroni confidence interval adjustment was used. Detrended fluctuation analysis (DFA) [5] measured the self-similarity of step intervals (locomotor system) and breath intervals (respiratory system). DFA (alpha) is a measure of long term correlation in a time series. An alpha value of 0.5 means no correlation is present from step to step, or breath to breath, whereas a value of 1.0 demonstrates a positive correlation over strides.

RESULTS AND DISCUSSION

Results from the DFA analysis are presented in figure 1. There was a significant difference between step interval alpha values for the baseline condition (condition 1) and the condition in which the participants were instructed to pace each step with the metronome beat (condition 4) ($p = 0.03$). There were no other significant differences observed between the conditions. There were no significant differences between breathing interval alpha values and the baseline condition.

Although significant interaction only occurred when the participants walked to a metronome beat, the other conditions tended to match the behavior of the given audio stimulus for that condition, primarily when participants were instructed to walk to the beat. Although no significant differences were observed in the breathing alpha values, breathing intervals were more correlated when breathing to a pink noise stimulus than breathing to a white noise and metronome stimulus.

In relation to the second research aim, the secondary (non-coupled) system was not changed. Breathing intervals were more correlated when walking to a pink noise stimulus than when walking to the other two stimuli. However, this was not observed in the walking intervals when breathing to the stimuli.

A standard metronome is often utilized in interventions that use an auditory stimulus to retrain a biological system (e.g., walking). The results of this study suggest walking to a metronome significantly affects that natural walking behavior. Although the results from linear tools from previous studies may suggest an improvement [6], the use of a non-linear tool such as DFA reveals the true effects.

Possible explanations for the limited significant differences include, the small sample size, cognitive and physical load on the participants, and small data lengths for the breathing intervals.

CONCLUSIONS

Participants were only able to match the behavior of the auditory stimulus when instructed to walk to the beat of a metronome, as walking behavior significantly decreased toward the stimulus' behavior compared to baseline walking behavior.

Interventions that utilize an auditory stimulus to "re-train" a biological system may not be best benefited by the use of a standard metronome. Instead, an auditory stimulus similar to the natural behavior of the physiological system (pink noise) may be better.

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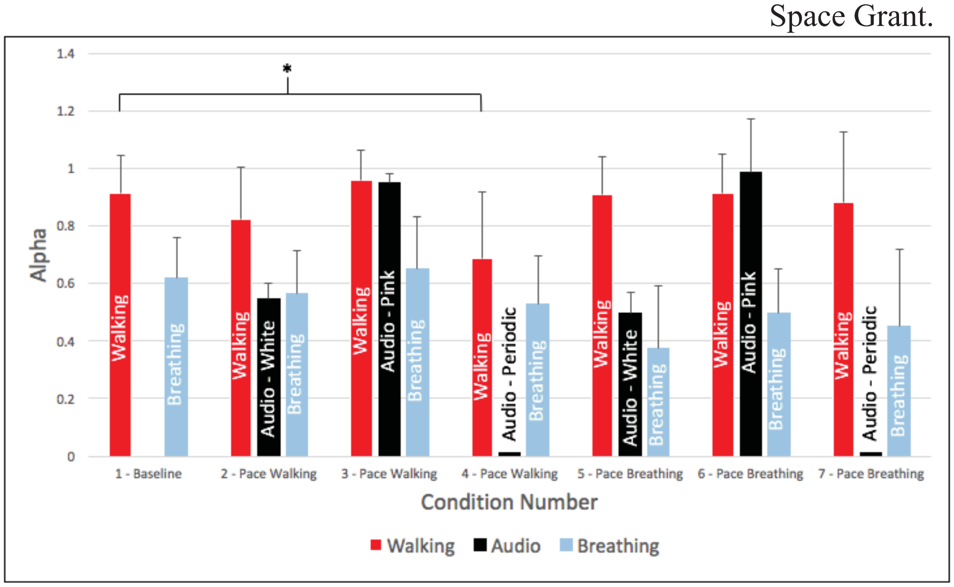

Figure 1: Alpha values for step (walking), beat (audio), and breathing intervals for each condition. Type of condition (given instruction) displayed below bars. Walking to the beat of a metronome had a significant effect on the walking interval correlations (*p* = *0.03*).

PARTITIONING ANKLE AND FOOT POWER DURING HUMAN MOVEMENT

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INTRODUCTION

The adaptable structures of the ankle and foot play a pivotal role in how we walk. The combined functions of these structures are analogous to a spring that absorbs/stores mechanical energy during ground contact and generates/returns energy to propel our body forward. Due to the complex anatomy of the ankle and foot, it has been difficult to isolate or partition the sources of mechanical energy production - especially within the various segments of the foot.

Recent investigations have revealed disparate energetic profiles in different subsections of the foot. Distal to the forefoot, the metatarsal-phalangeal joints act to dissipate/absorb energy during push-off [1,2]. Within the longitudinal arch, the surrounding muscle-tendon structures undergo stretch-shortening to absorb/store and generate/return energy [3]. Further investigation of various isolated subsections within the foot is expected to expand our understanding of the fundamental structure-function relationships that govern the way we walk.

Here, we aimed to quantify ankle and foot power in a segment-by-segment manner. We experimentally isolated the forces acting on various segments within the foot (hallux, forefoot, hindfoot) [1], and used an analysis based on non-rigid mechanics [4] to quantify power/work contributions of various subsections of the ankle and foot.

METHODS

We conducted a re-analysis of walking data from fourteen, healthy pediatric subjects (9 males; age 13 ± 3.07yrs; height 157 ± 17cm; weight 51 ± 17kg; mean ± SD) [1]. 10-camera motion capture system (Vicon) and force platforms (AMTI) were used to collect kinematic (sampled at 120 Hz) and kinetics data (sampled at 1560 Hz). We used a multi-segment foot model [1] to estimate segment motions of the shank and three segments within the foot: hindfoot, forefoot, and hallux.

To isolate the forces acting on each foot segment, subjects targeted their foot placement over two adjacent force platforms in three separate trials. First, subjects placed the forefoot-hindfoot segments on the posterior platform and the hallux on the anterior platform. Second, subjects placed the hindfoot on the posterior platform and the forefoot-hallux segments on the anterior platform. Third, subjects placed their entire foot (hindfoot-forefoot-hallux segments) on one force platform. The targeted foot placement in these three trials did not substantially alter the kinematics of the involved segments [1].

We quantified power/work contributions of various ankle-foot subsections by using a unified deformable (UD) segment analysis [4]. The UD analysis quantifies the summed contributions from all structures distal to a reference segment. For example, when the UD analysis is applied at the shank segment, it captures the summed contribution of the ankle joint and all foot structures. When the UD analysis is applied at the hindfoot segment, it captures the summed contribution of heel pad deformation, mid-tarsal joint, metatarsal-phalangeal joint, and hallux segment.

By performing separate UD analysis at four different segments (shank, hindfoot, forefoot, and hallux), this approach enabled partitioning of power/work contributions of ankle and foot structures in a piece-by-piece manner. For each segment level, we computed the total positive work, negative work, and net work (i.e., summation of positive and negative work).

RESULTS AND DISCUSSION

All subsections of the ankle and foot structures exhibited disparate power/work profiles (Figure 1). Distal to the shank (i.e., contribution from the entire ankle-foot), these structures produced near equal magnitudes of positive and negative work (net work of -0.014 ± 0.054 J/kg), signifying an energy-neutral system analogous to a spring. Other subsections within the foot produced relatively smaller positive work and contributed to net negative work.

Distal to the hindfoot (i.e., contributions from heel pad, mid-tarsal joint, metatarsal-phalangeal joint, and hallux segment), these structures absorbed energy in early stance and then generated/returned energy during push-off (with net work of -0.046 ± 0.024 J/kg). Distal to the forefoot (i.e., contributions from metatarsal-phalangeal joint, and hallux segment), these structures mainly absorbed energy during push-off (net work of -0.084 ± 0.034 J/kg). Distal to the hallux, magnitudes of positive and negative work were relatively small (net work of -0.006 ± 0.023 J/kg).

CONCLUSIONS

Our segment-by-segment approach offers a comprehensive view of the overall power/work production of the ankle and foot structures during walking. While the overall ankle-foot complex functions like an energy-neutral spring [5], the various subsections of the foot have different mechanics throughout walking [1-3]. We are currently conducting further analyses to compare our segment-by-segment technique to more traditional joint-based power/work estimates [1]. These efforts will enhance our current understanding of the structure-function relationships of the ankle and foot.

Our segment-by-segment approach may also be applicable to study ankle-foot mechanics in a wide range of clinical populations, including individuals with wearable devices (such as prostheses, orthoses, exoskeletons, and shoes) and individuals with abnormal foot structures (e.g., pes planus).

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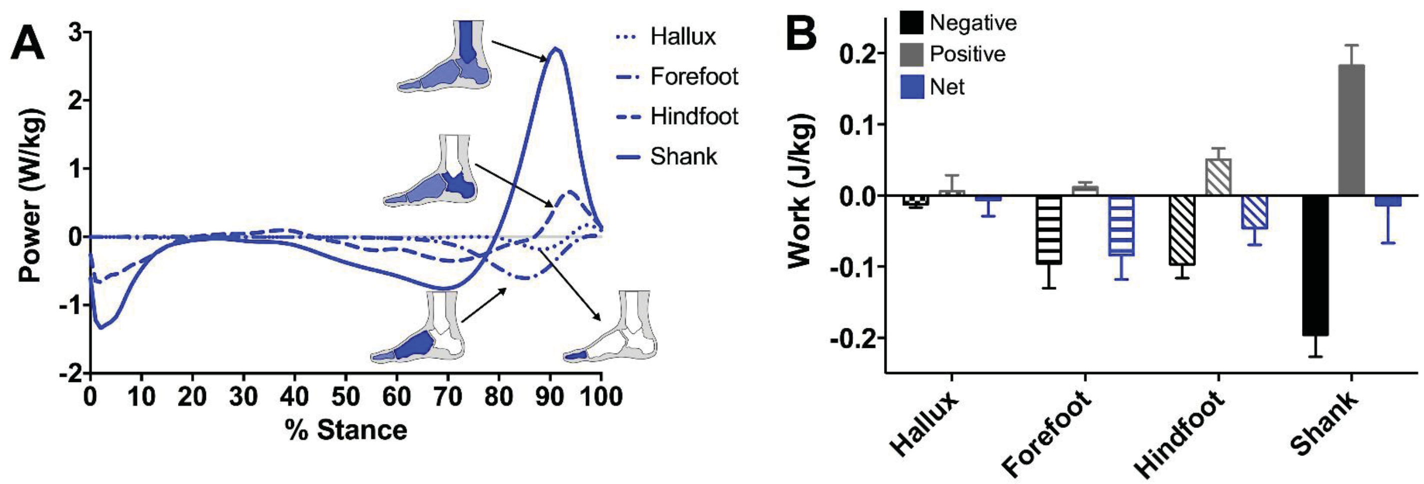

Figure 1: **A)** Cohort's mean (N = 14) power profiles from all structures distal (light blue) to a reference segment (dark blue). **B)** Cohort's mean ± SD of negative (black), positive (grey), and net (blue) work (normalized to body mass) performed by structures distal to a reference segment. Distal to the shank, the overall work profiles show a negative net work for the ankle-foot structures in the stance period of walking.

IS SCALE INVARIANCE PERSISENT FOR SUBSECTIONS OF LONG WALKING TRIALS?

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INTRODUCTION

Gait in healthy subjects exhibits complex stride-to-stride fluctuations. It has been assumed that time series of walking data possesses the property of scale invariance, meaning the same information should exist for both short (200 strides) and long (2000 strides) time series. Detrended fluctuation analysis (DFA) characterizes scale invariance and is commonly used to study the effects that different movement disorders and walking conditions have on the patterns of walking variability [1,2]. The purpose of this investigation was to determine whether common theoretical assumptions of scale invariance for relatively short time series persist when compared to longer walking time series for both over-ground and treadmill conditions.

METHODS

Footswitch data from a previous investigation was collected from 14 unimpaired subjects, but subjects whose footswitch data contained any signal dropout were excluded in this analysis. Therefore, this investigation included 10 subjects (7 females) from the original cohort. Mean age was 24.86 (SD 4.17) years, mean height was 1.17 (SD 0.12) m, and mean mass was 69.40 (SD 16.85) kg. Approval to conduct this prospective study was granted by the local Institutional Review Board. All subjects provided written informed consent prior to study enrollment.

Each participant walked with shoes for two, one-hour sessions: over-ground at a self-selected speed around an indoor track (1/8 mile per loop) and on an instrumented treadmill at their self-selected, comfortable speed. To reduce any influence of subjects initially adjusting to the walking condition, the first 50 strides were removed from all subjects' data. The subject with the shortest number of strides was then used as the total number of strides (2560) for all subjects to ensure all subjects had an equal number of samples. These 'full' length stride time data from these two walking conditions were then divided into shorter subsections of increasing increments of 50 stride time samples. The first subsection started with 100 samples, yielding a total of 54 subsections.

A custom Matlab program was used to calculate DFA alpha values (α_{DFA}) for all subsections and the full length time series [1]. The following DFA parameters were used: box sizes ranging from 10 to N/4, where N is the total number of stride time samples in the time series being analyzed. The mean square roots of detrended residuals, F(n), of the time series for different boxes of length n were calculated from 12 evenly spaced points in log-log coordinates. The evenly spaced DFA was chosen because it provides better estimation of scale invariance for short time series. Cronbach alphas from intra-class correlations (ICC) were calculated to determine how similar a subsection was to the full time series. Additionally, one-way repeated measures ANOVAs were run to test whether the full time series were significantly influenced by sampling a subsection.

RESULTS AND DISCUSSION

This retrospective study sought to investigate the assumption that scale invariance of stride times, as measured by DFA, persists for short and long time series by comparing long walking trials (2560 samples) to smaller subsections of the original time series. All of the one-way repeated measures ANOVA tests found that there were no significant differences between the full length time series and the subsections. In contrast, ICC results revealed a significant influence of time series length on the DFA exponent when compared to the full length time series. The Cronbach alpha values from the ICC comparisons of the full time series to each subsection are provided in Figure 1. A dashed horizontal line for an ICC Cronbach alpha of 80% is provided as a reference [3], along with markers to delineate fractional divisions of the full time series.

In order for the group to have at least 80% similarity to their full-length trials, this cohort needed to walk over-ground until at least 1150 stride time samples were recorded. For treadmill walking, this group needed to walk until at least 1900 stride time samples were recorded before they reached 80% similarity with the full length treadmill trial (2560 samples).

CONCLUSIONS

ANOVAs results support the continued used of DFA for group comparisons, but ICC results demonstrate that while there may not be statistically significant differences in subsections of the full length time series, scale invariance may not persist for shorter time series generated from walking parameters (e.g. stride time). Furthermore, the persistence of scale invariance in walking depends upon the walking condition and type of walking parameter being analyzed. While the original dataset did not record data to calculate stride lengths, we expect that if this analysis was repeated for stride lengths the number of samples necessary to reach 80% similarity to the full time series might be different compared to the samples needed for stride times [4]. Understanding these theoretical limitations of scale invariance when applied to actual walking data has important implications (e.g. duration of walking, number of samples) for future study design when exploring this property in walking.

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ACKNOWLEDGEMENTS

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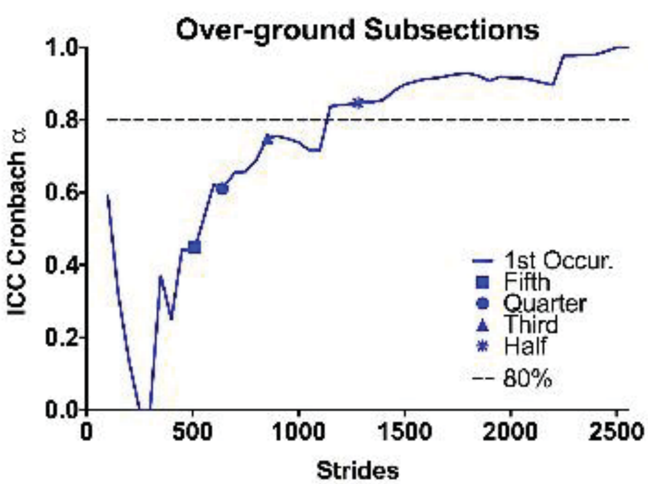

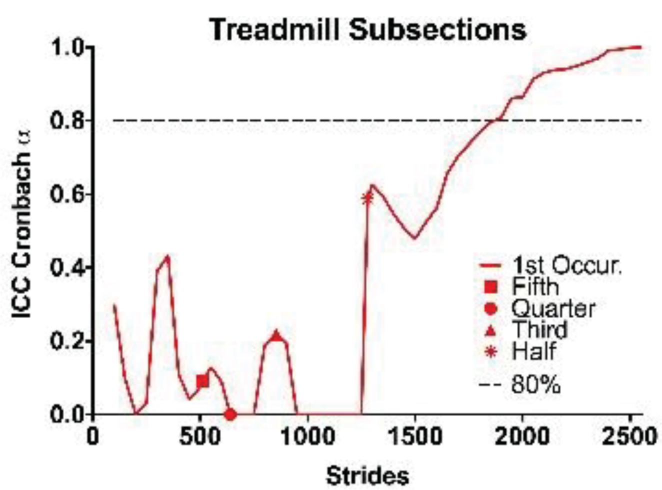

Figure 1: Cronbach alphas from ICC comparing subsections of the full length walking trial, starting at 100 and increasing in increments of 50 strides, to the full length (2560 strides) time series for over-ground (A) and treadmill (B) conditions. Dashed horizontal line indicates threshold for 80% similarity to full length time series (2560 samples), square indicates 1^{st} fifth, circle indicates 1^{st} quarter, triangle indicates 1^{st} third, star indicates 1^{st} half of full length time series.

DEVELOPMENT OF LOW COST 3D PRINTED TRANSITIONAL PROSTHESES

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INTRODUCTION

There are increasing numbers of children with traumatic and congenital amputations or reductions. Children's prosthetic needs are complex due to their small size, constant growth, and psychosocial development (Krebs et al., 1991 and Zuniga et al. 2015). Families' financial resources play a crucial role in the prescription of prosthetics for their children, especially when private insurance and public funding are insufficient. Electric-powered (i.e., myoelectric) and body-powered (i.e., mechanical) devices have been developed to accommodate children's needs, but the cost of maintenance and replacement represent an obstacle for many families. Due to the complexity and high cost of these prostheses, they are not accessible to children from low income, uninsured families, or to children from developing countries (Krebs et al., 1991 and Zuniga et al. 2015). Advancements in computer-aided design (CAD) programs and additive manufacturing offer the possibility of designing and printing prostheses at a very low cost (Zuniga et al. 2015). The purpose of the present investigation was to demonstrate the manufacturing methodology of 3D printed transitional prostheses, examine improvement in perceived changes in quality of life, daily usage, and activities performed with these types of devices.

METHOD

Nine children (two girls and seven boys, 3 to 16 years of age) with upper-limb reductions (one traumatic and eight congenital) were fitted with our 3D printed transitional prostheses and were asked to complete a survey. Inclusion criteria included boys and girls from 3 to 17 years of age with unilateral upper-limb reductions. Exclusion criteria included upper extremity injury within the past month and any medical conditions that would be contraindicated with the use of our 3D printed prostheses prototypes, such as skin abrasions and musculoskeletal injuries. The study was approved by the Creighton University Institutional Review Board and all the subjects completed a medical history questionnaire. All parents and children were informed about the study and parents signed a parental permission. For children 6 to 17, an assent was explained by the principal investigator and signed by the children and their parents. The survey was developed to estimate the impact of our prosthetic device including items related to quality of life, daily usage, and type of activities performed

RESULTS

After approximately 1 to 3 months of using our 3D printed prostheses 11 children and their parents reported some increases in quality of life (4 indicated that was significant and 7 indicated a small increase), while 1 indicated no change. Nine children reported using the device 1 to 2 hours a day, 3 reported using it longer than 2 hours and 1 reported using it only when needed. Furthermore, children reported using our 3D printed prostheses for activities at home (9), just for fun (10), to play (6), for school activities (4), and to perform sports (2). Four children reported malfunctioning and/or breaking of the 3D printed prosthetic device.

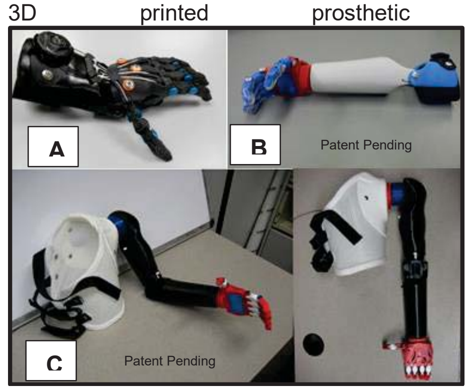

Figure 1. Shows some of the 3D printed transitional prostheses prototypes developed by our research team. A: Hand prosthesis (Cyborg Beast); B: Below Elbow Device; C: Prosthetic Shoulder.

DISCUSSION

The main finding of our survey was that our 3D printed transitional prostheses have a great potential in positively impact quality of life, daily usage, and can be incorporated in several activities at home and in school. However, 36% of our research participants reported durability issues and/or malfunctioning of these devices. There is a need to develop medical grade 3D printed prosthetic devices to solve the durability constrains.

CONCLUSION

Although, durability and environment are factors to consider when using 3D printed prostheses, the practicality and cost effectiveness represents a promising new option for clinicians and their patients. 3D printing technology for the development of prosthetic devices is at a very early stage. The supervision of a certified prosthetist is crucial for the proper development and use of 3D printed prostheses.

CLINICAL APPLICATIONS

3D printed transitional prostheses have a great potential in positively impact quality of life, daily usage, and can be incorporated in several activities at home and in school. The supervision of a certified prosthetist is crucial for the proper development and use of 3D printed prostheses.

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INCREASES IN ROM AND CIRCUMFERENCE OF THE FOREARM AFTER 6 MONTHS OF USING A 3D PRINTED TRANSITIONAL HAND PROSTHESIS

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INTRODUCTION

Children's prosthetic needs are complex due to their small size, constant growth, and psychosocial development (Krebs et al., 1991 and Zuniga et al. 2015). Independent of the type of limb deficiency (congenital or traumatic) muscle atrophy, loss of mobility, and asymmetry are typical characteristic of the affected limb (Krebs et al., 1991 and Zuniga et al. 2015). Most upper-limb prostheses for children include a terminal device, with the objective to replace the missing hand or fingers. Electric-powered units (i.e., myoelectric) and mechanical devices (i.e., body-powered) have been improved to accommodate children's needs, but the cost of maintenance and replacement represent an obstacle for many families (Krebs et al., 1991 and Zuniga et al. 2015). The development and use of low-cost transitional prosthetic devices to increase ROM, strength, and other relevant clinical variables would have a significant clinical impact in children with upper-limb differences. Thus, the purpose of the study was to identify anthropometric, active range of motion, and strength changes after 6 months of using a wrist driven 3D-printed transitional prosthetic hand for children with upper limb differences.

METHOD

Subjects: Five children (two girls and three boys, 3 to 10 years of age) with absent digits (one traumatic and four congenital) participated in this study and were fitted with a low-cost 3D-printed prosthetic hand.

Apparatus: Anthropometric, active range of motion, and strength measurements were assessed before and after 6 month of using a low-cost 3D printed prosthetic hand.

Procedures: Six variables from the affected and non-affected hand including circumferences, skin folds, and active ROM for flexion, extension, radial deviation, and ulnar deviation were measured on each research participant by a trained occupational therapist.

Data Analysis: Seven separate two-way repeated measures ANOVAs [2 x 2; hand (affected versus non-affected) x Time (before and after)] were performed to analyze the data. A p-value of $\leqslant 0.05$ was considered statistically significant for all comparisons.

RESULTS

There were significant hand × time interactions for the forearm circumference [$F(1,4) = 16.90$; $p = 0.02$], active ROM flexion (Fig. 1) [$F(1,4) = 12.70$; $p = 0.02$,], and active ROM extension values [$F(1,4) = 8.80$; $p = 0.04$]. There were no significant hand x time interaction, however, for wrist flexion strength [$F(1,4) = 1.48$; $p = 0.29$], wrist extension strength [$F(1,4) = 0.05$; $p = 0.84$], active ROM UD [$F(1,4) = 0.65$; $p = 0.5$], active ROM RD [$F(1,4) = 1.77$; $p = 0.25$], and forearm skinfold values [$F(1,4) = 4.24$; $p = 0.11$].

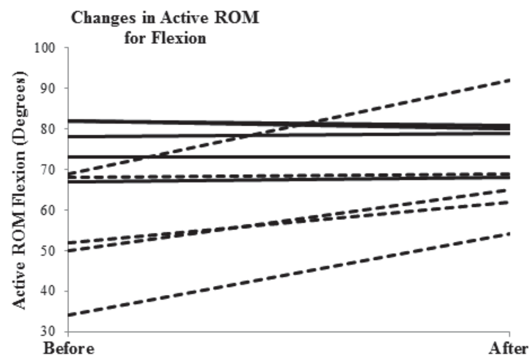

Figure 1. shows individual changes for active range of motion (ROM) for wrist flexion before and after a 6 month period of using the low-cost 3D printed transitional prosthetic device.

DISCUSSION

The main finding of the present investigation was that the usage of a low-cost 3D printed transitional prosthetic hand significantly increased forearm circumference (Before=16.70±1.86 cm and After=17.80±1.48 cm), wrist active ROM flexion (Before=54.60±14.48° and After=68.40±14.29°), and active ROM extension (Before=40.40±37.75° and After=47.00±36.42° cm) on a small sample of children with upper-limb differences. Thus, the Cyborg Beast transitional prosthetic hand represents low-cost prosthetic solution for those in need of a transitional device to increase ROM.

CONCLUSION

Although, durability and environment are factors to consider when using 3D printed prostheses, the practicality and cost effectiveness represents a promising new option for clinicians and their patients.

CLINICAL APPLICATIONS

Six month of using this 3D printed transitional prosthesis increased forearm circumference, wrist active ROM flexion, and active ROM extension in children with upper-limb differences.

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DESCRIPTION AND COMPARISON OF SCALING PROCEDURES IN COMPUTER DESIGN PROGRAMS (BLENDER AND FUSION 360) FOR 3D PRINTED PROSTHESES

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INTRODUCTION

Three-dimensional (3D) printing is a process of making a 3D solid object of virtually any shape from a digital model. Scaling is the process by which the prosthetic device designs are correctly sized for each subject. This is done by importing an image of patient affected and unaffected areas juxtaposed to a measuring device into a design program and using the image as reference to size the imported file of the prosthetic device design in the same program. Advancements in computer-aided design (CAD) programs offer the possibility of fitting transitional 3D printed prostheses at a distance. Blender, a computer design program, has been used to scale and fit prostheses. Newer CAD programs, such as Fusion 360, may improve and simplify the distance fitting procedure. The goal of this project was to describe and compare the fitting abilities of Blender and Fusion 360. Prostheses were scaled for ten human subjects using both programs, and all the scaled devices were measured within Fusion 360. The measurements of the devices were analyzed for differences using t-Tests. Analysis has validated Fusion 360's ability to scale to the ability of Blender and has provided support for Fusion 360's improved and more user friendly scaling procedure when compared to that of Blender.

METHOD

The description and comparison process of Blender and Fusion 360, which is still in progress, has been partially achieved by scaling the Cyborg Beast palm prosthetic device designs (left or right palm depending on subject) in Blender and Fusion 360 for ten subjects. Seven of the subjects have already been given devices scaled in Blender. Three of the subjects have prosthetic devices scaled in Fusion 360. The palm design used to scale for all ten subjects was scaled separately for each subject in both programs; twenty scaling procedures were made in total. The known scale sizes for subjects with Blender scaled devices were used to rescale the original palm in Blender and scale in Fusion 360. The scale size recently found for newer subjects with Fusion 360 scaled devices was used to rescale the original palm in Fusion 360 and scale in Blender. The repetition of scaling assisted in understanding the scaling procedures for both programs and improving the Blender scaling process, as well as comparing and identifying positive and negative aspects of both procedures and programs. A written narrative description of both program scaling procedures is in process. After the devices were scaled, the devices were measured along various dimensions (length, width, height, diagonal, and diameter of a hinge hole) in Fusion 360; the devices scaled in Blender were imported into Fusion 360 for this procedure. Excel was used to record these measurements and perform t-Tests to reveal any significant differences in the measurements of palms scaled in Blender and Fusion 360.

RESULTS

The results of the dependent t-Tests indicate that there are no mean differences between the measurements taken from the two different scaling procedures using Blender (length mean 73.5636 mm ± standard deviation (SD) 12.60029 mm, width mean 79.9135 mm ± SD 13.7711 mm, height mean 45.4539 mm ± SD 7.662897 mm, diagonal mean 106.1892 mm ± SD 18.1291 mm, and diameter of a hinge hole mean 5.9734 mm ± SD 1.073923 mm) and Fusion 360 (length mean 73.6363 mm ± SD 12.66254 mm, width mean 80.6532 mm ± SD 13.78627 mm, height mean 45.6159 mm ± SD 7.718721 mm, diagonal mean 107.0615 mm ± SD 18.65409 mm, and diameter of a hinge hole mean 5.9774 mm ± SD 1.02784 mm). These results indicate that the hand prostheses scaling procedures performed in Fusion 360 are not significantly different than those performed in Blender. These results would allow the performance of digital distance fitting procedures in two different computer design programs.

DISCUSSION

It can be concluded that Fusion 360 scales to the same ability as Blender. This allows both programs to be used for scaling. Blender and Fusion 360 have qualities that could be considered negative and positive. Fusion 360 seems to be an improved, more user friendly, and more intuitive program, especially in regard to the calibration processes of the scaling procedures.

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