Friday May 21st			
Start Time (UTC)	**Finish Time (UTC)**	**Event**	**Presenter**
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Thelan		MACHINE LEARNING FOR DIAGNOSING PERIPHERAL ARTERY DISEASE	Mohammad Ali Takallou
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Thelan		THE EFFECT OF HANDRAIL USE ON KNEE JOINT LOADING, BALANCE, AND CONFIDENCE WHEN NEGOTIATING STAIRS IN INDIVIDUALS WHO ARE OBESE	Todd Leutzinger
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Gilbreth		IMPROVED FUNCTIONAL OUTCOME AND DECREASED BRAIN ACTIVATION FOLLOWING VIRTUAL REALITY TRAINING: A CASE STUDY	Sheridan Parker
Manzolini		EVALUATION OF EMPIRICAL MODE DECOMPOSITION AND LOW PASS FILTER FOR NONLINEAR ANALYSIS OF STEP AEROBIC EXERCISES	Yassaman Djafari
Manzolini		THE RESPONSE OF UPPER LIMB PROSTHESIS USERS TO A SIMULATED TRIP: A PILOT STUDY	Clare Severe
Broer		NONLINEAR ANALYSIS OF PATIENT/EQUINE DYNAMIC INTERACTION IN HIPPOTHERAPY: A CASE STUDY	Amin Kazemi
Broer		APPLICATION OF NONLINEAR DYNAMICS TO STUDY FATIGUE BEHAVIOUR DURING RUNNING WHILE WEARING COMPRESSION GARMENTS	Kourosh Bajelani

Poster rooms shown in the right column above next to the poster title.

INTRINSIC GAIT VARIABILITY OF KINEMATIC VARIABLES IN CHILDREN AND YOUNG ADULTS WITH CEREBRAL PALSY: METHODOLOGICAL AND CLINICAL CONSIDERATIONS

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Presentation Preference: **Podium**

INTRODUCTION

Intrinsic gait variability, i.e. fluctuations in the regularity of gait patterns between repetitive cycles, is inherent to the sensorimotor system and influenced by factors such as age, walking speed and pathological conditions [1]. Increased gait variability in cerebral palsy (CP) might be a marker of gait impairment thus a conclusive parameter when interpreting clinical gait analyses (CGA). In contrast to variability studies of spatiotemporal parameters, the variability of kinematic parameters remains largely unexplored.

The aim of this study is to better understand kinematic gait variability of the lower limbs in children and young adults with CP while 1) describing the pathology specific gait variability pattern of nine kinematic variables and 2) identifying the explanatory variables of the variability pattern observed.

METHODS

273 CGA (patients n=166, age 12.27+/- 4.83, GMFCS I-III) were analyzed. Root mean square deviation (RMSD, cf. Figure 1) was computed for nine kinematic variables. Gait Standard Deviation (GaitSD) was considered as composite variability score for the lower limb. Correlation was performed on RMSD. Univariate and multivariate linear regressions were performed on GaitSD for age, gait deviation index (GDI) and clinical parameters (selectivity, force and passive range of motion).

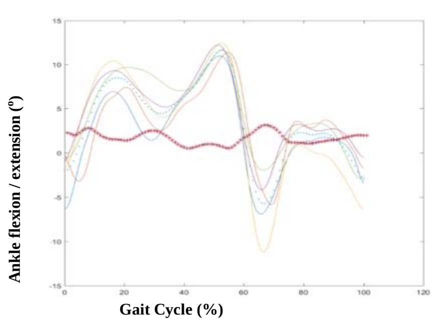

Figure 1: *Example of kinematic variability, red line: RMSD. Each curve (continuous line) represents one gait cycle (n=5). The dotted blue line represents the mean of all 5 cycles*

RESULTS AND DISCUSSION

The sensitivity analysis revealed that GaitSD was stable after 5 cycles. RMSD of all nine kinematic variables were correlated (r>0.41, p<0.05). The highest values of RMSD were found in the transverse plane and in the sagittal plane (Figure 2). GaitSD was associated with age (p<0.001), GDI (p<0.001), GMFCS (p<0.001) and force (p<0.01).

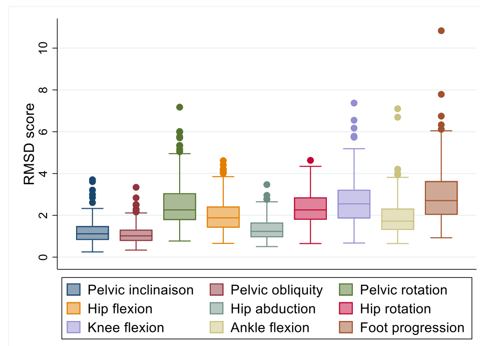

Figure 2: *Cycle-to-cycle (n=5) RMSD for nine kinematic variables*

Increased variability for the foot progression angle can result from several highly variable movements in the transverse plane. Increased variability in the sagittal plane (hip and knee) can be due to increased range of motion and acceleration characteristics [2]. The strong correlation between the RMSD of the kinematic variables could be explained by the physiological and functional synergy of joint movements when walking [2, 3].

CONCLUSIONS

Due to the strong correlation of the RMSD of lower-limb kinematic variables, CP related variability could be expressed as a global entity (GaitSD) and explained by both, maturation of our target population as well as clinical symptom severity. Further studies are needed to confirm the clinical relevance of kinematic variability measures and evaluate the effectiveness of possible therapeutic interventions targeting it.

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ACKNOWLEDGEMENTS

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Machine Learning for Diagnosing Peripheral Artery Disease

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Presentation Preference: [**Podium**]

INTRODUCTION

Peripheral artery disease (PAD) is a manifestation of atherosclerosis producing blockages in the leg arteries. Although the diagnosis of PAD in its early stage increases the chance of slowing disease progression and decreases the risk of major cardiovascular events, 40-60% of patients with PAD go undiagnosed in a primary care setting.

The current medical exams for diagnosing PAD, primarily measuring ankle-brachial index (ABI), are specialized tests that are costly and performed by technologists with special training in a vascular lab[1]. Our previous work using advanced biomechanics revealed walking patterns that are characteristically different compared to older controls without PAD. The purpose of this study was to leverage characteristic biomechanics differences to develop machine-learning models that support diagnosis of PAD.

METHODS

Recently researchers have implemented data-driven approaches using machine-learning for PAD diagnosis from clinical records, questionnaires, and symptom scores. However, this approach did not consider gait as an input variable. The models also have significant limitations in terms of accuracy, time, and resources.

We will use existing data from previous projects studying gait in patients with PAD.[2,3] Data from 20 patients with PAD patients and 8 healthy control subjects of the gait data were analyzed. The gait data includes gait biomechanics and distance features collected for subjects while performing controlled experiments in a lab-setting environment.

We focused on using biomechanics data. We cleaned and preprocessed the raw data from the biomechanics gait dataset to deal with missing data and discard noisy and redundant data. Next, we applied the dimensionality reduction approach to find a new coordinate system in which the input data can be represented with fewer features without losing significant information (feature extraction, and feature selection). We evaluated the accuracy of machine learning models such as support vector machine (SVM), logistic regression (Logit), and deep neural networks (DNN) to predict patients with PAD.

RESULTS AND DISCUSSION

Our initial preliminary results (Figure 1) show that using the most dominant biomechanics features produces models able to predict PAD with 89-97% accuracy.

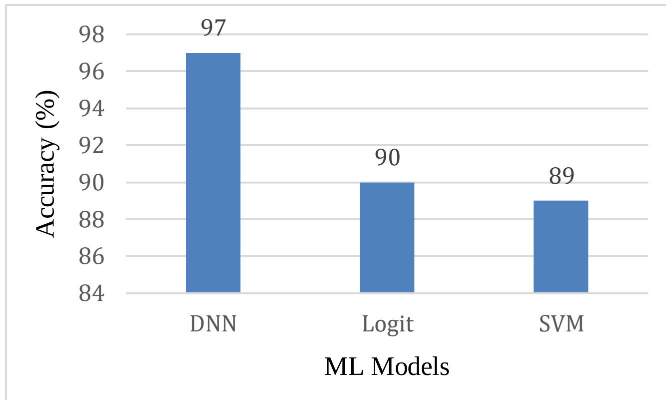

Figure 1: Our preliminary results shows that using 35 out of 41 biomechanics features to train different machine learning models achieve an accuracy up to 97%. In this experiment, we split the dataset into 75% training, and 25%

CONCLUSIONS

Data driven approaches are promising to support the diagnosis of PAD, especially when combined with clinical data, and symptoms. Future work will use transfer of knowledge to develop models for PAD diagnosis from physical activity data extracted from acceleration data captured in subjects' natural environments.

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ACKNOWLEDGEMENTS

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IMPROVEMENT IN WALKING SPEED FOLLOWING REVASCULARIZATION SURGERY IN PATIENTS WITH PERIPHERAL ARTERY DISEASE

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Presentation Preference: **Poster only**

INTRODUCTION

Peripheral artery disease (PAD) is characterized by limited blood flow to the limbs due to narrowed peripheral arteries. As a result of blocked vessels, active muscles cannot get adequate blood flow during walking, which leads to ischemia and pain known as claudication.

Revascularization surgery restores blood flow to the vessels, , reduces the pain from walking, and increases life expectancy in patients with PAD [1]. The effectiveness of this procedure in improving function can depend on the patient's disease severity and revascularization success. Treatment efficacy is usually expressed as statistical comparisons of outcomes such as leg vessel blood flow, quality of life questionnaires, walking distances, mortality, amputation etc. obtained from pre- and post-treatments. However, these comparisons do not capture how individuals benefit or whether those changes are significant.

Minimal clinically important difference (MCID) defines the smallest change in an outcome measurement that is significant and relevant on an individual level [2]. Walking speed is a quick and an easy measurement that can be implemented in a clinical setting. The objective of this study is to estimate the MCID in walking speed in patients with PAD following revascularization surgery.

METHODS

Experimental Data Collection

Patients with PAD were recruited through the vascular surgery clinic of Nebraska Western Iowa Veteran Affairs Medical Center and underwent for revascularization by board certified vascular surgeons. Patients were evaluated before (*baseline*) and six months after revascularization treatment (*post-surgery*) at the Biomechanics Research Building at the University of Nebraska at Omaha. Patients completed the Medical Outcomes Study 36-item Short Form Questionnaire (SF-36) as a subjective assessment of quality of life. Patients then walked across a 10-meter pathway while recording a heel reflective marker on the leg most affected with PAD. Coordinates of the reflective marker were recorded using a 12 high speed infrared camera system (60 Hz, Motion Analysis Corporation, Rohnert Park, CA).

MCID calculation

Data for fifteen patients will be analyzed for this study. We will first calculate the walking speed as the average distance traveled per second from the reflective marker. MCID in walking speed will be estimated in two ways: i) distribution-based and ii) anchor-based methods. For the distribution-based method, a small improvement will be computed as 0.2 x σ and a substantial improvement will be computed as 0.5 x σ, whereas σ is the standard deviation of the baseline walking speed [2].

For the anchor-based method, two mobility questions from the SF-36 will be used: i) ability to walk one block and ii) ability to climb one flight of stairs. Participants rated their ability as *limited a lot*, *limited a little*, and *not limited at all* while answering those two anchor questions. Patients will be categorized in groups (substantial improvement, small improvement, no change) based on their responses to these two anchor questions for baseline and post-surgery. Mean change in walking speed between these groups will be reported as an estimate for the MCID in walking speed [2].

EXPECTED RESULTS

The results will provide the MCID values for small and substantial improvements based on the distribution and anchor-based methods.

The outcomes of this study will provide information on the functional significance of improvements patients with PAD experience from revascularization. This knowledge will be useful for clinicians in interpreting the clinical significance and whether improvements following revascularization surgery are meaningful.

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ACKNOWLEDGEMENTS

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The Effect Of Handrail Use On Knee Joint Loading, Balance, And Confidence When Negotiating Stairs In Individuals Who Are Obese

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Presentation Preference: [**Poster**]

INTRODUCTION

Previous research has shown approximately 80% of US children and adults do not get adequate amounts of physical activity in a day[1]. Meyer et al., (2009) demonstrated that taking the stairs at work can increase daily physical activity and improve cardiovascular fitness, body composition, blood pressure, and lipid profiles in inactive adults [2]. Unfortunately, stair negotiation is often avoided when alternative methods are available [3]. This tendency to avoid stair use may be the result of a lack of strength, cardiovascular fitness, lower extremity joint pain, poor balance, and/or a fear of falling [4]. One common technique used to improve self-efficacy of stair negotiation is the use of a handrail [5]. However, the effect of handrail use on biomechanical factors during stair negotiation is largely unknown. The purpose of this study is to develop a critical understanding of the effect of handrail use on knee joint biomechanics during stair negotiation in healthy young adults.

METHODS

Five individuals (height:1.73 $\pm$ 0.11 m, weight:65.11 $\pm$ 10.34 kg, Age: 25.2 $\pm$ 5.72) participated in both stair ascent and stair descent walking trials involving three handrail conditions: 1) no support, 2) light support handrail use, and 3) self-selected handrail use. Study participants performed five trials for each condition at a self-selected walking pace on an instrumented staircase with three 6 degree-of-freedom force plates and instrumented handrails (Bertec Corp, Columbus, OH). Force data were collected at 1000 Hz using the force plates and handrails. Fifty-seven retro-reflective markers were placed on the subjects' extremities and torso and marker data were collected using a 12-camera motion analysis system at 100-Hz (Qualysis Track Manager, Göteborg, Sweden). For both stair ascent and stair descent, the stance phase of the step occurring on the second stair was analyzed [6]. Analog force plate data was used to calculate net internal sagittal plane knee joint moment through an inverse dynamics solution using Visual 3D (C-Motion, MD). A One-way repeated measures analysis of variance (ANOVA) test was performed to determine differences in sagittal plane knee joint moment between the three handrail conditions for both stair ascent and stair descent.

RESULTS AND DISCUSSION

No significant differences were found in peak knee extension moment ($p = 0.14$) or peak knee flexion moment ($p = 0.43$) during stair ascent. Similar results were found during stair descent with no significant differences between conditions for the first ($p = 0.36$) or second ($p = 0.60$) knee extension moment peaks (Figure 1). These results indicate that handrail use does not alter sagittal plane knee joint moments in healthy young adults. However, previous research has shown individuals with weak lower extremities muscles alter knee joint kinetics when using the handrail by decreasing the ankle joint moment and increasing the knee joint moment [7]. This is thought to be a consequence of the ankle joint working closer to its maximum capacity during stair ascent compared to the knee joint without handrail use. Therefore, it is important to investigate how varying degrees of handrail use effect knee joint kinetics in other populations.

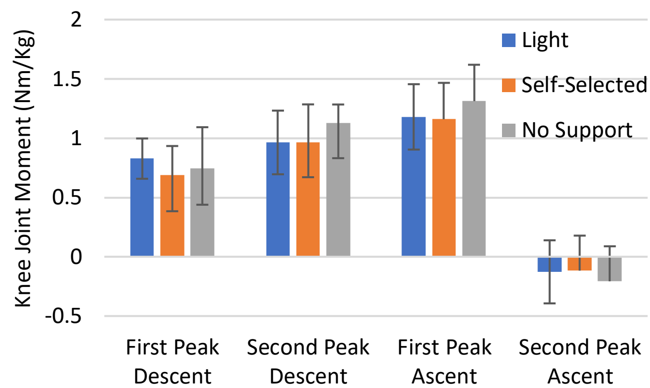

Figure 1. Peak knee extension moment normalized to body mass during the first and second half of stance phase while descending the stairs.

CONCLUSIONS

The use of a handrail does not appear to alter sagittal plane knee joint moment in healthy young adults during stair use. However, this abstract only includes preliminary findings from a pilot sample and results should be interpreted with caution. Moreover, previous research has shown the use of a handrail offloads the ankle joint and puts excess stress on the knee joint [7]. Future research is needed to determine the effect of varying degrees of handrail use on knee joint kinetics in other populations with health complications.

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ADAPTATION OF DIVERGENCE EXPONENTS FOR REAL-TIME FEEDBACK

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Presentation Preference: **Podium**

INTRODUCTION

Real-time feedback has a long history of being used to successfully improve movement. The use of technology has enabled augmented feedback of spatiotemporal measures, joint kinematics, and ground reaction forces for improving performance in sports [1], and balance [2]. While augmented feedback of linear measurements is useful for modifying gross movements, nonlinear measures offer a unique approach to help train movement patterns. However, nonlinear measures have not been widely applied in real-time feedback. This is partially because algorithms to calculate these measures rely on long time series to obtain stable results. One measure, the maximum Lyapunov Exponent, quantifies the mathematical stability of a time series. Here we will briefly explain an effort to adapt this measure, and introduce a similarly behaved divergence exponent (DivE) that has potential in real-time feedback.

METHODS

A total of nine participants (8 males, 1 female) were enrolled in this study (height = 181.278 ± 9.162 cm, weight = 85.379 ± 13.161 kg). This study was approved by the Institutional Review Board at the University of Nebraska Medical Center and the U. S. Army, Human Research Protection Office.

Participants walked on a treadmill (Bertec Corp, USA) for 2 min. Kinematics were recorded with an 8-camera motion capture system (T160, Vicon Motion Systems, UK) and 65 surface markers. Hip, knee, ankle, shoulder and elbow sagittal plane joint angles were calculated in Visual3D (C-Motion, USA). DivE were calculated in MATLAB 2020a (MathWorks, USA) with publicly available code [3,4]. This method uses various secondary parameters, including one called scale-max [4]. This is a threshold calculated as 10% of the data's range [3,4]. In working to adapt this method for real-time application, we found interesting influences of the scale-max term. To investigate this, we calculated DivE for all joint angles using scale-max values from 0.1% to 1000% of the data's range.

RESULTS AND DISCUSSION

The scale-max parameter has an important effect on the DivE with potential conflicts in interpretation. It is clear that large changes in DivE can result from small changes to scale-max (Figure 1). Specifically, cross-overs between all angles can be found between the asymptotes. Curiously, some trends between the ankle-knee-hip are similar to differences in the literature between the competing Wolf et al and Rosenstein et al -methods [4,5]. A plateau effect is also noticeable at small and large percentages. To simplify the calculation of DivE and apply it in real-time the effect of scale-max needs to be considered. Its effect on DivE calculations should also be considered when interpreting results. If stable values are obtained with small or large values, then it could be beneficial to set this parameter to a small or large percentage of the range, or remove it.

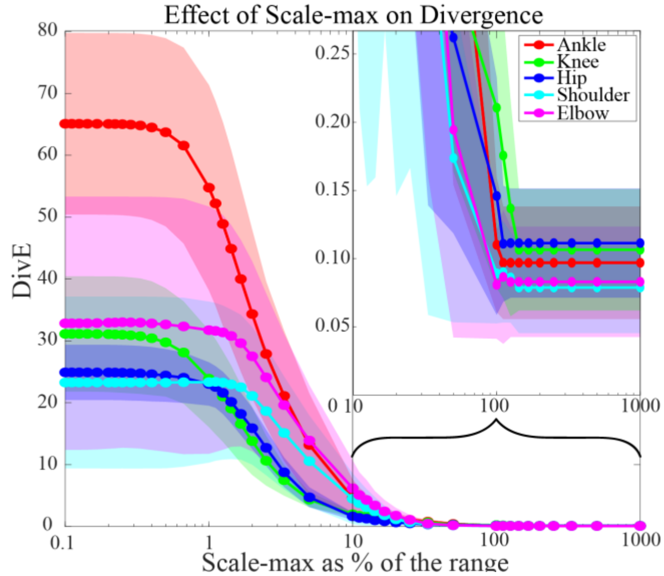

Figure 1: Different proximal-to-distal trends can be seen at the asymptotes. The vertical line marks the typical value for the Wolf et al method [4]. Colored boundaries represent ±1 STD.

CONCLUSIONS

In order to apply nonlinear methods such as Divergence Exponents (DivE) to real-time applications their computationally intense procedures will need to be adapted. One way to do this is to simplify the computational methods. In this example that effort revealed the importance of a secondary parameter, scale-max, on the calculation of DivE. This parameter and its effects could produce different trends that result in conflicting interpretations. If very low or high values of scale-max are also found to have a stabilizing effect on other time series, then it could be beneficial to zero this parameter and its effects from the calculation of DivE.

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DESIGN OF A LOW-COST UNILATERAL HIP BRACE FOR GAIT TRAINING

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Presentation Preference: **Poster**

INTRODUCTION

Asymmetric gait patterns, found in many individuals with neurological diseases (e.g., post-stroke patients, Multiple Sclerosis patients), consist of reduced preferred walking speed, lower extremity range of motion, and step length [1,2]. Many rehabilitation practices have been implemented to try to combat these asymmetric patterns. One method we have yet to research extensively in asymmetric gait is error augmentation, during which errors are increased during walking gait [3]. The brain learns through experiencing errors, and research has shown that training with a device that augments errors results in preferable gait patterns after the intervention [3,4]. Expanding research on the concept of error training may help provide new rehabilitation protocols for asymmetric walking patterns.

Although robotic exoskeletons have proven successful at influencing the kinetics and kinematics of walking gait [4,5], the time needed to set up such devices, prepare the subject, and the cost of materials are extensive. Passive exoskeletons greatly reduce the cost of materials and provide a less time-consuming method for manipulating walking gait. Creating a simple device to manipulate asymmetric gait patterns may provide clinicians an easy-to-implement rehabilitation practice that targets the impaired limb compared to more expensive options, such as split-belt treadmill training, that are not as readily available. Therefore, the purpose of this abstract is to discuss the development of a unilateral hip brace for gait training. The long-term objective is to use this passive exoskeleton to influence asymmetric gait patterns in a future research study.

METHODS

We used two surfer calf straps (SBS) to create the knee connection of the exoskeleton. The straps connect via Velcro around the calf. Two TheraBand® pieces construct the elastic element of the exoskeleton. The bands connect to the knee brace via carabiner hooks. A Proflex® back brace with suspender straps built-in composes the hip attachment point where carabiner hooks are used once again to connect the bands proximally to the brace.

RESULTS AND DISCUSSION

The proposed unilateral hip brace is based on a design by Neuman et al., seen in Figure 1. This unilateral device successfully assisted hip flexion during walking gait in patients with Multiple Sclerosis, showing the design's effectiveness [2]. However, the bands used on the intended unilateral hip brace will be stretched past the optimum to create more errors during walking gait. Studies with exoskeletons show that increasing assistance above the optimal level for the device impedes walking [6]. Therefore, using the bands as an impedance instead of for assistance creates a way to impose error augmentation on walking gait. The bands are placed on the front of the thigh to resist hip extension during gait.

Figure 1: Example of a previous design (left) of a unilateral exoskeleton and the design of the proposed exoskeleton (right) [2].

ACKNOWLEDGEMENTS

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PREDICTING A WINNER FROM TEAM COORDINATION DYNAMICS

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

INTRODUCTION

Predicting sports games outcomes is an endless pursuit shared by stakeholders ranging from fans to coaches to data scientists. Researchers commonly use regression and other data mining tools to attack this problem. Basketball game outcomes have been predicted using combinations of traditional box statistics with up to 88% accuracy. Such algorithms need to be trained with years of data to predict game outcomes to this level [1]. While this statistical method can be useful, it is possible that years of historical data may not be available in amateur teams who do not have the same lineup stability as professional teams. We approached this problem from a team coordination perspective by analyzing the "shape" of team movements on the court. Time series analysis used in the study of team coordination has shown temporal correlations are present when a system flexibly adapts to changing circumstances [2]. Hence, we hypothesized that consistency of a team's shape over time may indicate better team coordination and, ultimately, better team performance. That is, we expected that the team with more shape consistency would win more often.

METHODS

Elite male junior basketball player's 3D positional data was captured using the ShotTracker local positioning system (ShotTracker, Kansas City, KS) during 10 games at the 2018 NBA Academy Games held at the Australian Institute of Sport.

De-identified data for each game was divided into "Team A" and "Team B" for each of the 10 recorded games. Player data was collected for the entire game. Player X and Y position coordinates were filtered, using the known court dimensions, to only contain players that were within the bounds of the court. An area polygon implied by the five players on each team was then calculated at each time point during the game. All area time series obtained for full games, first half and second half, were subjected to detrended fluctuation analysis (DFA). DFA measures correlation in time series over time and returns a value, α. An $\alpha \approx 1$ indicates positive time correlation. An $\alpha \approx 0$ indicates negative correlation, and an $\alpha \approx 0.5$ indicates no correlation. Analyses were done in R (R Core Team (2020)).

RESULTS AND DISCUSSION

DFA results from the full game time series showed that the team with a higher α won 60% of the time (Figure 1). Results also showed that if the halves are analyzed on their own, then the win percentage increased to 70%. Based on this pilot work, a few remarks are warranted. First, the granularity of the analysis may be important, given that we saw better predictive performance looking at individual halves. Game strategies may vary from period to period. By analyzing the halves (college) and quarters (pro) independently, a coach may better detect the influence of decisions on game outcomes at a more meaningful level. Second, the sample size was relatively small, but the results are promising. Win percentages based on period-level analyses approached levels obtained from machine learning models trained on years of data [1]. Increasing sample size may reveal additional insights.

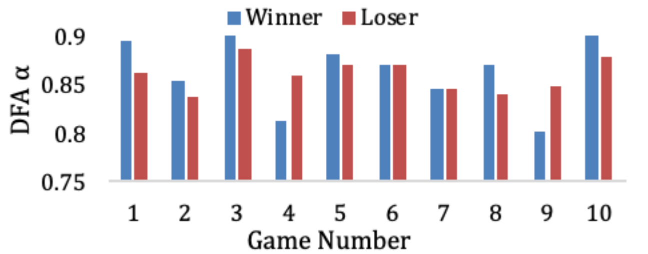

Figure 1: Bar chart of α by Game Number. The team with the higher α for the whole game has a 60% chance of winning.

CONCLUSIONS

The results show that analysis of team shape provides insight into the structure of team coordination dynamics that predict winning a game. These preliminary results show that analyzing time-varying correlations in team area is a potentially accurate means to predict outcomes. In fact, our approach may be more accurate than some traditional regression equations [1]. From a theoretical perspective, the metric (a single number) we have developed may indicate something akin to team cohesion. In an applied setting, a coach could use this metric for deeper understanding of team performance resulting from, for example, team lineups and formations. Future work will explore different analysis granularities and techniques to better understand team coordination.

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EXAMINATION OF DYNAMIC STABILITY DURING VARIOUS SLIPS ON TURNS

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Presentation Preference: **Poster**

INTRODUCTION

Turning constitutes up to 45% of all steps we take each day [1] and requires elevated shear ground reaction forces [2] and, in turn, required coefficients of friction from the ground [3] to execute. These requirements likely increase the chance of slipping beyond that of straight, level walking. However, far less is known about the consequences of slips on turns compared to those on a straight path. One such gap is in the application of stability measures, which have been used to evaluate slip severity and recovery performance. We have shown that the context in which a slip occurs greatly influences the mechanics of the perturbed foot [4]. Therefore, the aim of this study was to determine the influence of different slip contexts on dynamic stability after a turning slip.

METHODS

The following protocol was approved by the Institutional Review Board of the University of Nebraska Medical Center. 18 healthy, young adults (22.72 ± 2.89 yrs., 1.73 ± 0.09 m, 72.25 ± 12.35 kg, 9 females) gave written informed consent to participate and completed all study procedures. Subjects wore a compression suit, fall-arresting safety harness, full-body retroreflective marker set, standardized athletic shoes instrumented with Pedar-X plantar pressure insoles (Novel GmbH; Munich, Germany), and a Wearable Apparatus for Slip Perturbations (WASP) [5] on each foot. All participants performed 12 slip trials, with each using a unique combination of turn radius (1.0 m, 2.0 m) slipped foot relative to the turn (inside, outside), and slip onset phase during stance (early, mid, late stance). Subjects walked at a self-selected comfortable speed along the prescribed path for a randomized duration between 30 seconds and 3 minutes. After this time, a slip perturbation was delivered to the targeted foot at the prescribed phase by an attending investigator. Following the slip, subjects were allowed a seated rest while the activated WASP was reset. Full-body kinematics were recorded via motion capture system (Motion Analysis Corp.; Santa Rosa, CA) at 200 Hz, while synchronous plantar pressure data were sampled at 100 Hz.

To quantify dynamic stability, the margin of stability (MoS) concept proposed by Hof et al. [6] was used. Center of mass (CoM) position and velocity in the horizontal plane were derived from kinematic data. CoM velocities were divided by a factor that accounts for the force of gravity and the subject's leg length and added to the CoM position to get the extrapolated center of mass (XCoM). Center of pressure (CoP) location was obtained from the Pedar data. Because the Pedar-calculated CoP is in reference to a two-dimensional, insole-based coordinate system, it was first transformed into the three-dimensional global coordinate system [7] of the CoM and XCoM. The shortest distance from the XCoM to the CoP is taken as the MoS. An average, normalized MoS time series for unperturbed stance phases was calculated this way and served as a baseline to which slip trial MoS time series were compared. The difference between baseline and the minimum MoS between slip onset and compensatory step touchdown, which we hereafter call MoS deviation, was used as our outcome measure.

A linear mixed model was employed to assess the influence of turn radius, slipped foot, and onset phase on MoS deviation, with each entered as a fixed effect and subject as a random effect. The critical alpha for all tests was set at $\alpha = 0.05$.

RESULTS AND DISCUSSION

This study is currently in the data analysis phase, therefore we do not have final results to share at this time. However, we do expect to find a significant negative correlation between slip onset phase during stance and the MoS deviation from the unperturbed baseline during the slip (i.e. early > mid > late stance). Furthermore, we hypothesize that inside foot slips will elicit significantly greater MoS deviations than those to the outside foot relative to the turn. Finally, we predict that the MoS deviation will be larger during slips on 1.0 m radius turns than 2.0 m radius turns.

The findings of this study could offer insight into the destabilizing effects of a broad range of realistic, unconstrained slips on turns. Because the MoS accounts for the motion state of the CoM, it will provide a glimpse into the slips' effects on the upper body. This builds upon past work by our lab that only examined the distal effects on the slipping foot [4]. Furthermore, the majority of past research has focused on perturbations on straight walking paths. Our results should contribute to a more comprehensive understanding of slip recovery in commonly encountered situations.

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This work was supported by NIH grants R15AG063106 and P20GM109090 and a GRACA grant from the UNO Office of Research and Creative Activity. The authors would like to thank Andrew Walski and Ciera Sanwick for their assistance in data collection and processing.

IMPROVED FUNCTIONAL OUTCOME AND DECREASED BRAIN ACTIVATION FOLLOWING VIRTUAL REALITY TRAINING: A CASE STUDY

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Presentation Preference: **Poster**

INTRODUCTION

Previous literature has reported that virtual reality (VR) as a neuro-rehabilitation tool for stroke survivors has reported increases in functional task performance over a single session [1,2]. We can measure functional task improvements and rehabilitation outcomes using the box and block test (BBT) and functional near-infrared spectroscopy (fNIRS). fNIRS measures the change in cortical blood oxygenation by detecting differences in the absorption of near-infrared light between oxygenated (HbO) and deoxygenated blood (HbR) [3]. fNIRS has emerged as a practical neuroimaging technique to assess hemodynamic responses and cortical organization as it is less sensitive to movement artifacts, portable and provides good spatial resolution [3]. Therefore, the purpose of this study is to determine the changes in motor cortex activation and functional outcomes following a VR training (VRT) intervention. We hypothesize that there would be an increase in the number of blocks moved and a decrease in motor cortex activation following the VRT intervention.

METHODS

A case study was performed with a participant with chronic stroke (age: 55 years, height: affected hand: left) participated in the study. The individual signed an approved consent form, and the study was approved by the University of Nebraska Medical Center Institutional Review Board.

At baseline, the participant was asked to complete the BBT both manually and in VR (Oculus Rift, Oculus, Menlo Park, CA USA) under observation with functional near-infrared spectroscopy (fNIRS, Nirsport 2, NIRx, Berlin, Germany). fNIRS was used to measure activation of the left and right motor cortices throughout the data collections. The fNIRS cap was positioned over the Cz vertex of the head with an 8x8 sensor-detector montage resulting in twenty measurement channels. The participant was asked to first complete the BBT manually using their less affected and affected hands for three trials each, respectfully. The participant was then asked to complete the BBT in VR using their less affected and affected hands for three trials each, respectfully. Rests were given between each trial. The participant then completed twelve weeks of VRT at a rehabilitation clinic. A post-training collection was performed using the same baseline collection procedures.

Using raw fNIRS data in the NIRS AnalyzIR toolbox [4], 30 seconds before and after the last trial was removed. The raw data was then resampled and converted to HbO and HbR concentrations using a modified beer lamber law. A general linear model (GLM) analysis was applied to the hemoglobin concentrations with an auto regressive-iterative least squares (AR-ILS) function, to obtain levels of activations, β values, for each measurement channels [4]. Four paired tests were performed comparing the baseline to post-training β values for manual and VR BBT performed with the affected and less affected hands. Data and statistical analyses were performed in Matlab (Mathworks, Natick, MA USA) with a significance level of alpha ≤ 0.05.

RESULTS AND DISCUSSION

Following VRT, the participant was able to increase their BBT score with their affected hand by 1 block for the manual condition and increase their score by 3 blocks for the VR condition. This increase was noticeable as the participant was not able to complete any blocks with their affected hand at baseline. This indicates that the VRT is able to produce clinically relevant functional improvements. Furthermore, motor cortex activation decreased during the VR condition compared to the manual condition for both the affected ($p=0.04$) and less-affected ($p=0.01$) hands. following VRT. Our results suggest that there is potential evidence for motor skill consolidation with VR training.

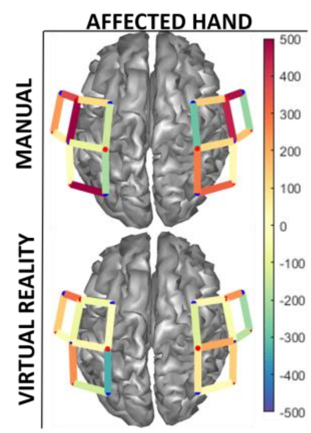

Figure 1. Change in motor cortex activation between baseline and post-training for the affected hand when performing the BBT manually (top) and in VR (bottom).

CONCLUSIONS

Virtual reality training has potential functional and motor cortex activation benefits for individuals with chronic stroke. The use of VRT has advantages a home-based program that could be used by individuals with limited transportation means to get to rehabilitation and for individuals that would benefit from a meaningful home program with increased repetition.

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Evaluation of Empirical Mode Decomposition and Low Pass Filter for Nonlinear Analysis of Step Aerobic Exercises

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

INTRODUCTION

Human locomotion is inherently nonlinear and thus requires suitable data acquisition and processing techniques. Wearable IMU units are commonly used to obtain nonlinear kinematic time series. The preprocessing stage contains steps to address several concerns such as sensor inherent noise, noise originating from skin artifacts, offset and slow nonlinear trend which should be removed to ensure stationarity.

The empirical mode decomposition (EMD) is used to decompose the time series into its vibrational modes, thus allowing the elimination of the slow nonlinear trend and low frequencies with high energy. The approach, however, needs to be evaluated in both time and frequency domains.

The combination of detrending and low pass filters are also used to remove both offset and trend while smoothing the time series. Performance of the low pass filter could also be affected by the input coefficient involved in the acausal expression.

Therefore, the objective of this article is to investigate the effect of both EMD and input coefficient (in the low pass filter), on time and frequency domain features, and hence on the interpretation of nonlinear system characteristics.

METHODS

To investigate the effects of EMD and input coefficient on time and frequency domain features, 10 participants (age 25.7±3.2) were selected to perform a 4-minute bout of stepping using a 9cm aerobic step. Total body movement was recorded using a single IMU mounted on SI representing the center of mass. Nonlinear dynamic characteristics such as approximate entropy were determined using the obtained kinematic data.

A low pass filter was applied to hip anterior/posterior acceleration time series in the first approach. Robust cosine detrending method was then implemented, resulting in a smooth detrended time series. History dependency of the current state, in human movements, necessitates an acausal low pass filter expression, as shown in expression (1).[3]

$$output[i] = 0.9 \times output[i-1] + a \times input[i] \qquad \textbf{expression (1)}$$

The acausal filter could adopt five different values (0.1, 0.01, 0.001, 0.05 and 0.005) for input coefficient (a). Cycle detection was performed using peak finding method, and the number of samples in each cycle was normalized to the sampling frequency. Calculation of five different embedding dimensions were used to calculate five different values for approximate entropy. [1]

The effect of low pass filter was further investigated through evaluation of time and frequency domain features. Spectrum magnitude was used to visualize the effect of filtering on the frequency domain, and SDNN (Standard Deviation of peak-peak intervals) reflect how the filter altered signal's total variability.[2]

In the second approach, the empirical mode decomposition (EMD) method was applied to the raw data (hip anterior/posterior acceleration time series), resulting in the elimination of the first and last vibrational modes, as well as, the slow nonlinear trend. Approximate entropy was subsequently determined following a similar methodology to that of the first approach. Frequency and time-domain features were also determined using spectrum magnitude and SDNN, similar to the first approach.

RESULTS AND DISCUSSION

The first approach results indicate that both variability and spectrum magnitude are reduced as the input coefficient is reduced. In other words, the system variability is least altered when input coefficient of 0.1 is adopted. However, when the input coefficient is set to 0.05, almost all amplitude spectrum peaks were attenuated. Furthermore, the approximate entropy was not affected and did not change as the input coefficient was changed.

The second approach results illustrated that implementation of EMD results in a severe reduction of system variability and power spectrum density. The approximate entropy exhibited changes of less than 5%.

Figure 1 represents the effect of the filter on variability and regularity of time series. Higher variability is illustrated by the size of the circles in this Figure.

Therefore, it could be concluded that a low pass filter with the input coefficient set at (0.1) proved more effective than EMD. Low pass filter results in a more regular time series while keeping the state space structure, the embedding dimension and variability intact. Application of the EMD, on the other hand, has not changed the time series irregularity but increased embedding dimension and reduced variability.

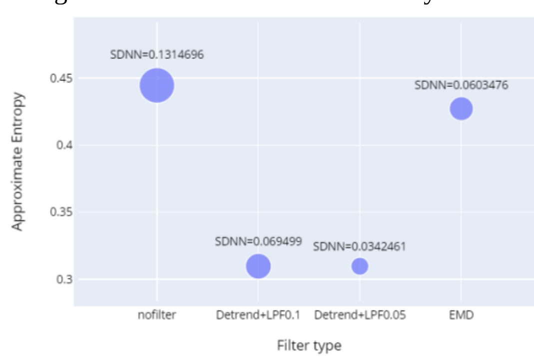

Figure 1: Effect of filter on variability and regularity of time series.

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THE RESPONSE OF UPPER LIMB PROSTHESIS USERS TO A SIMULATED TRIP: A PILOT STUDY

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Presentation Preference: [**Podium**]

INTRODUCTION

Nearly half of persons with major upper limb loss (ULL) experience at least one fall per year [1] and almost a third will report an injury due to their most recent fall [1]. This evidence suggests that falls represent an important but often overlooked health hazard to this patient group. Importantly, while 25% of falls result from a trip, use of an upper limb prosthesis (ULP) increases likelihood of frequent falls (at least twice per year) by six times [1]. Additional biomechanical studies align with these findings on fall prevalence to suggest that persons with ULL experience impaired postural control and locomotor stability [2,3]. This pilot study aimed to characterize the locomotor response of persons with ULL to a simulated trip and assess effects of prosthesis use on that response.

METHODS

After obtaining written informed consent, one male participant with unilateral transradial ULL (57 yrs, 178.0 cm, 95.8 kg, myoelectric prosthesis user) completed two tasks while walking on a custom treadmill (Motek, the Netherlands) and wearing a safety harness: 1) baseline walking at his self-selected speed and 1.0 m/s, and 2) 12 perturbation trials. Both tasks were completed under two prosthesis conditions: with and without wearing his ULP. For each perturbation trial, an unexpected treadmill belt disturbance was delivered while the participant walked at 1.0 m/s and during single limb support of either the sound or impaired limb side (six on each side but randomly selected). Following a randomly selected step (between 21 and 40), the belt experienced a symmetric acceleration (up to 3.3 m/s over 400 ms) and deceleration back to 1.0 m/s. Perturbation trials ended after the participant regained steady walking and then completed 20 strides. Full-body kinematic data were collected with an optical motion capture system (Motion Analysis, CA) and custom marker set. A subject-customized biomechanical model in Visual 3D (C-Motion, MD) was used to estimate sagittal-plane whole-body angular momentum (*WAM*), trunk inclination (*TI*), and trunk inclination velocity (*TV*) *pre*- and *post*-perturbation.

RESULTS AND DISCUSSION

The participant successfully recovered from all perturbations without a fall (i.e., full harness arrest). Example instantaneous TI, TV and WAM (normalized by body mass, height and walking speed) for one perturbation trial are shown in Fig. 1.

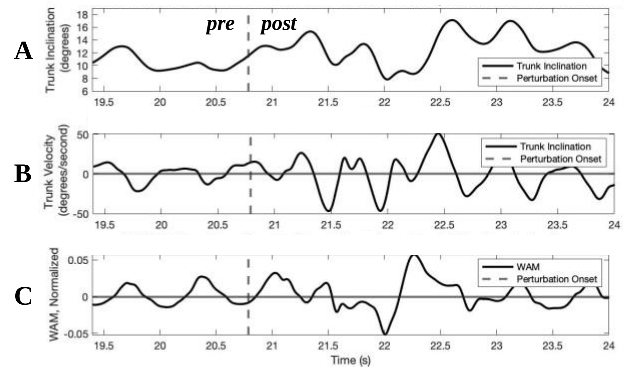

Figure 1: TI (A), TV (B) and WAM (C) for a perturbation trial (without ULP, impaired side leg); +ive=forward rotation.

Average max TI, max TV and WAM range across five trials (removing the first on both limb sides) are in Table 1. The perturbation induced a forward trunk lean (Fig 1A/B), the magnitude of which was similar across all conditions. However, the trunk rotated forward faster and had a greater change from pre-perturbation behavior when perturbed during sound side single support. As intended, the perturbation generated a clear disturbance to WAM regulation (Fig 1C) and while there was a greater post-perturbation WAM range when perturbed during sound side single support that aligned with trunk velocity changes, WAM range was considerably higher when the participant did not wear his prosthesis. Overall, findings suggest an asymmetric locomotor response following a trip disturbance that may share an interaction with ULP wear and could help us better understand the mechanisms underlying fall risk in this patient group. Data collection is ongoing.

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Table 1: Maximum TI, maximum TV and WAM range (mean±SD) separated by prosthesis condition and perturbation side.

		With Prosthesis		Without Prosthesis	
		Sound Side Perturbation	Impaired Side Perturbation	Sound Side Perturbation	Impaired Side Perturbation
TI (°)	*pre*	13.8±0.6	13.7±0.8	13.6±0.4	13.5±0.3
	post	17.7±1.3	17.3±0.7	17.0±1.6	15.7±1.2
TV (°/s)	*pre*	22.5±1.3	22.2±1.4	23.8±0.7	23.6±0.7
	post	40.0±6.6	31.3±3.3	41.8±10.1	35.0±11.0
WAM (norm.)	*pre*	0.045±0.001	0.036±0.021	0.047±0.001	0.045±0.001
	post	0.067±0.006	0.065±0.008	0.089±0.012	0.078±0.020

Nonlinear Analysis of Patient/Equine Dynamic Interaction in Hippotherapy: A Case Study

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Poster Presentation

INTRODUCTION

Hippotherapy is a treatment modality performed by highly trained physiotherapists. The dynamic interaction between the horse and the patient during hippotherapy has many positive effects on the patient's quality of life. However, only a limited number of biomechanical and kinesiological studies have addressed the intricacies involved in this highly complex dynamic interaction. Both human and equine locomotion are nonlinear in nature and therefore, the dynamics of patient trunk movement while attending a hippotherapy session can only be studied through nonlinear dynamic analysis. The first step in any such studies is to establish the basis for evaluating the patient trunk movement dynamical stability.

METHODS

A simulated hippotherapy session was conducted as a case study with a healthy adult (25 years old, 174 cm height, 64kg weight, and BMI=21.14) unfamiliar with riding horses. The experiment was based on walking horse gait for a distance of 20m in a shuttle test. A leader was responsible for handling the horse (as suggested by hippotherapy guidelines). This eliminated any muscular movements by the subject in controlling the horse. The subject was asked to maintain a sitting posture throughout the experiment. Linear accelerations and angular velocities in three dimensions were recorded using four IMU sensors (Xsens-Netherland). Three sensors were placed on bony landmarks of S1, T2, and T11 on the subject spine, while the final sensor was placed on the equine spine immediately behind the subject hip area (marker, h). Data acquisition took place at 50 Hz and data were transferred to the global coordinate frame using rotation matrices. Artifact elimination was achieved through the application of 4th order low pass Butterworth filter [1]. The cutoff frequency for each parameter was selected based on observation of the frequency spectrum, which led to the choice of cutoff frequencies between 5 to 11 Hz for different parameters.

Nonlinear analysis commenced with state-space reconstruction. Average Mutual Information and False Nearest Neighborhood algorithms were used to determine time delay and embedding dimension for state-space reconstruction. Embedding dimension was used to estimate the approximate entropy [2]. This parameter was used as the measure of dynamic stability in this experiment.

RESULTS AND DISCUSSION

The horse/subject dynamic interaction could be considered as a multi-linkage system. Trunk stability was identified by angular variations associated with flexion/extension on the sagittal plane. Approximate entropy was calculated for angular variations obtained from different sensors (h, S1, T11 and T2). Results from S1 to T2 could be interpreted that the motor control system tends to increase variability to maintain stability as you move up the spine. However, movement from h to S1, indicates a reduction in variability, which could be associated with stiffening core musculature in an attempt to maintain stability.

State-space graphs for θ_h and θ_{T11} are shown in (Figure 2). While state-space cycles seem more concentrated for θ_h, the approximate entropy illustrates that variability was higher in θ_h than in θ_{T11}. This result indicates that while in cyclic changes of the parameters, the mean value of θ_{T11} exhibits more occasional changes when compared to θ_h, the variability was found to be lower.

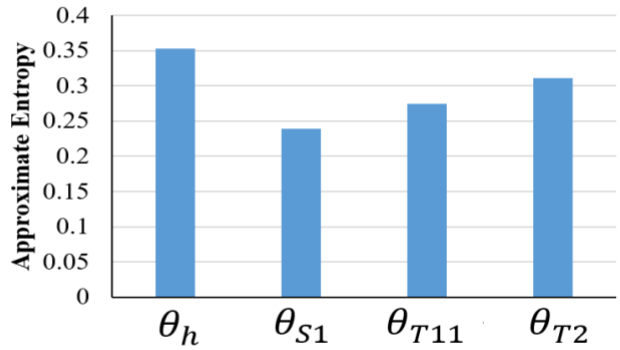

Figure 1: Approximate Entropy for flexion/extension in the sagittal plane for the horse (θ_h) and S1(θ_{S1}), T11(θ_{T11}) and T2(θ_{T2}) landmarks for the rider.

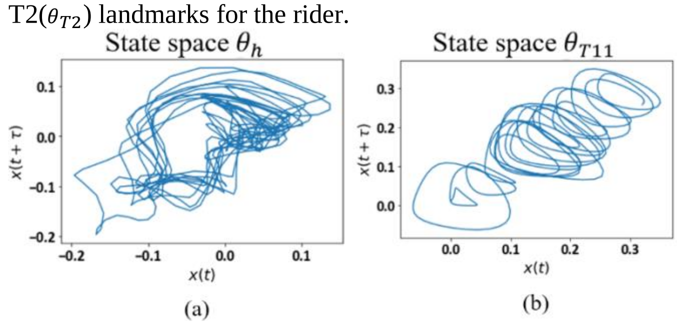

Figure 2: State-space graphs for a-θ_h and b-θ_{T11}.

CONCLUSIONS

The results suggest that the rider motor control strategy to maintain balance is to constraint hip variability using core musculature and increase the trunk variability. Although the path length was too short to maintain a stable pattern, the subject was able to stabilize his movements.

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Application of Nonlinear dynamics to study fatigue behaviour during running while wearing Compression Garments

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Presentation Preference: Poster

INTRODUCTION

Adoption of compression garments (CGs) in athletics and sport activities is becoming more widespread. CG pressure on muscles influences proprioception and blood circulation [1]. The aim of this research was to study fatigue development as a parameter to evaluate the influence of CGs on athletic performance. The effects of these garments may not be easily quantified using linear methods. Thus, study of changes in movements caused by fatigue requires more sophisticated tools such as nonlinear dynamical systems method [2] which is more capable of detecting subtle changes in complex nonlinear systems. In this paper, we propose a kind of PSW method named local flow variation (LFV), which uses 2D phase portraits and tracks the drifts occurring between trajectories.

METHODS

Fifteen healthy male athletes as the participants were asked to perform two sets of walking and running on a treadmill with and without CGs randomly. Each set commenced with a 5-minute walk at a speed of 5 km/h followed by running at 7 km/h for 10 minutes. A set of 21 passive reflective markers were placed at various anatomical landmarks.

Kinematic data provided by the motion analysis system were used to reconstruct phase portraits of the relationship between hip angle and hip angular velocity. To explore the local trajectory drifts caused by fatigue in the phase space, a multivariate method called smooth orthogonal decomposition (SOD) was applied. In SOD, we search for a linear projection (optimal) $\varphi = Xq$,to maximize variability and minimize fluctuations:

$$\max_{q} \lambda(q) = \frac{\|Xq\|^2}{\|DXq\|^2} \qquad (1)$$

In this expression, q represents the eigenvector or smooth orthogonal mode, D represents the differential operator and φ represents the optimal projection with smooth columns that describes the maximum variability in matrix X. The particular SOC with the highest corresponding eigenvalue (λ) or smooth orthogonal value (SOV) is called the dominant SOC which was subjected to nonlinear quantification of complexity (Permutation Entropy). PEnt scalar values of the test conditions were used for additional statistical analysis such as ANOVA.

RESULTS AND DISCUSSION

The overall fatigue trend followed by LFV (Figure 1) was described by a pseudo-linear monotonic trend in all SOC_1s. Effects of CGs on PEnt (non-linear) of SOC_1, is significant (p=0.012). The permutation entropy (Pent) for SOC_1 is reduced with CGs. The results reveal that running with CGs (p=0.029) reduced complexity of behaviour (less kinematic change in SOC_1 curves).

It is shown that adoption of CGs decreased the rate of fatigue development by decreasing the SOC_1 curve slope (Figure 1d).

The complexities encountered in SOC trajectories were analyzed by PEnt (panels in Figures 1d and 1h). It is shown that the entropy parameter is smaller with CGs. The implications are that the body exhibits a more limited complexity (more predictable, smaller fluctuations and lower SOC slope) while wearing the CGs. This complexity could reveal the intrinsic complexity of the interaction of the central/ peripheral mechanisms demonstrated in body kinematics.

The methodology has illustrated the positive effects of this type of garments on reducing the rate of fatigue development in running. The existing literature has predominantly relied on statistical and physiological analysis to evaluate the effect of CGs. In this article, similar results have been obtained through quantification methodologies. It is also shown that the garments have reduced movement complexity or increased regularity in fatigue development.

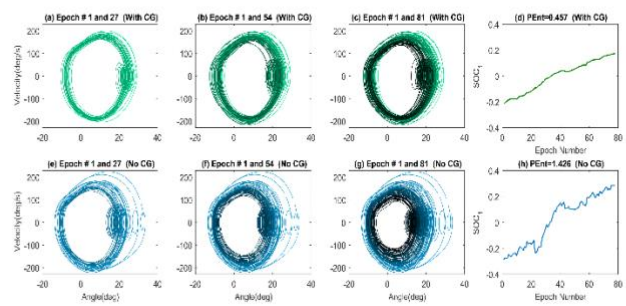

Figure 1: Figure 1 (a, b, c, e, f and g) epochwise plots of phase portrait trajectories of one participant to show gradual drifts caused by fatigue.

CONCLUSIONS

In conclusion, participants had smaller entropy parameter with CGs during running. The implications were that the body exhibited a more limited complexity (more predictable, smaller fluctuations and lower SOC slope) while wearing the CGs. The methodology has illustrated the positive effects of this type of garments on reducing the rate of fatigue development in running.

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