

Theme of Research: Movement Variability

Title: Decreased gait variability following anterior cruciate ligament reconstruction negatively impacts patient function.

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Purpose: Following anterior cruciate ligament (ACL) reconstruction 30-50% of individuals continue to demonstrate persistent impairments in strength and lower extremity biomechanics which negatively impact patient-reported function. There is an increased risk of recurrent injury and an earlier onset of knee osteoarthritis (OA). Following ACL reconstruction previous studies have demonstrated individuals have limited knee motion and increased movement variability. Findings from previous studies have limited clinical application since they only include male participants and do not describe impairments in context to patient function. The purpose of this study was to quantify differences in nonlinear measures of gait biomechanics in individuals within 2 years of ACL reconstruction compared to a healthy comparison group and to determine the relationship between gait biomechanics and patient-reported outcomes.

Methods: Fifteen individuals with a history of ACL reconstruction (11 female, 5 male; mean±SD age= 20.9±5.7 y; height= 172.8±7.9 cm; mass= 70.9±14.6 kg; time since surgery= 13.2±5.0 months; International Knee Documentation Committee subjective knee scale [IKDC]= 88.9±13.4) and twenty healthy participants (11 female, 9 male; age= 20.2±4.2 y; height= 175.6±9.6 cm; mass= 69.4±12.1 kg; IKDC= 97.2±4.3) volunteered for this study. Participants performed 2 minute bouts of walking and running at self-selected speeds. The primary outcome measures were sagittal plane movement variability (sample entropy) and IKDC subjective scores. Differences between limbs were expressed as a percentage using the LSI for descriptive purposes (involved/uninvolved ACL; nondominant/dominant healthy). Separate two-way mixed model ANOVAs were used to determine differences between sides (involved/uninvolved) and groups. The relationship between walking and running sagittal plane movement variability and IKDC scores was quantified using Pearson product moment correlations.

Results: Descriptive statistics are provided for walking (ACL involved= 0.1145 ± 0.0214, uninvolved= 0.1190 ± 0.0291, LSI= 0.98 ± 0.16; Healthy dominant= 0.1472 ± 0.0372, nondominant= 0.1369 ± 0.0409, LSI= 1.11 ± 0.20) and running (ACL involved= 0.3322 ± 0.0308, uninvolved= 0.3489 ± 0.0155, LSI= 0.95 ± 0.08; Healthy dominant= 0.3676 ± 0.0142, nondominant= 0.3665 ± 0.0173, LSI= 1.00 ± 0.03). There was not a significant group x side interaction for walking (F= 3.68, p= .07) and there was no main effect between groups for walking sagittal plane movement variability (F= 4.00, p= .06) and there was no difference

between sides (involved versus uninvolved) for individuals with ACL reconstruction ($t = -.93$, $p = .37$). There was a significant group x side interaction for running ($F = 6.53$, $p = .02$). Individuals with a history of ACL reconstruction had significantly lower ($F = 16.87$, $p < .001$) sagittal plane movement variability compared to healthy individuals, but there was no significant difference ($t = -1.88$, $p = .08$) between the involved and uninvolved limbs. There was a moderate relationship ($r = .657$) between IKDC scores and sagittal plane movement variability during running.

Conclusions: The results of this study suggest there are no differences between groups when examining sagittal plane movement variability during walking. Differences do exist when running and individuals with a history of ACL reconstruction demonstrate decreased movement variability in both limbs. Decreased variability manifests as more predictable movement, potentially increasing the risk of knee osteoarthritis. Additionally, decreased sagittal plane movement variability negatively impacts patient function as demonstrated by lower IKDC scores for individuals with decreased movement variability. Future studies should determine interventions which can address movement variability impairments.

Abstract Submission: Email Angela Collins at afcollins@unomaha.edu

EFFECTS OF ANKLE EXOSKELETON POWER AND ACTUATION TIMING ON MOVEMENT VARIABILITY AND METABOLIC COST OF WALKING

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Walking is one of the most primal movements and an essential part of everyday life. While humans use many strategies to reduce metabolic energy cost, walking still requires a considerable amount of metabolic energy. Lower extremity exoskeletons have become an established technology designed to reduce metabolic cost. Recently, it was reported that they might increase the variability of the locomotor system making the system more noisy and unstable, but optimal assistance properties for gait variability remain unclear. This could be a main concern for people with a mobility disorder. We investigated the effect of ankle exoskeleton power and actuation timing on gait variability and metabolic energy cost of walking. Data was collected for ten healthy participants wearing a powered ankle-foot exoskeleton during a 4-minute treadmill walking trial at $1.25 \text{ m}\cdot\text{s}^{-1}$ in ten different assistance conditions. Largest Lyapunov exponent (LyE) was calculated to quantify the pattern of stride-to-stride fluctuations of the ankle angle kinematics. The metabolic rate and LyE were compared between conditions. Optimal assistance was achieved at 42% of the stride and average power of $0.4 \text{ W}\cdot\text{kg}^{-1}$ for both the LyE and metabolic rate. This resulted to a 50% lower LyE and a 21%

reduction in metabolic cost compared to walking with the exoskeleton deactivated. These results emphasize the importance of optimizing exoskeleton actuation properties to provide a more stable and metabolic efficient human locomotor system.

Infants at High-Risk for ASD Exhibit Greater Fixation Durations than Infants at Low-Risk

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Autism Spectrum Disorder (ASD) is a neurodevelopmental syndrome that affects one in 68 children in the United States, a rate that has increased by 78% in the last decade. Currently, ASD is diagnosed at approximately four years of age, but the severity and recurrence of the symptoms make an earlier diagnosis imperative for earlier interventions to be administered. Thus, we are lacking quantitative ways to assess and diagnose ASD in the first years of life, so children at-risk for ASD are missing years of potential treatment. Currently ASD is diagnosed using qualitative measures regarding delays in social communication and the presence of restrictive repetitive behaviors. Recently, however, analyzing children's gaze patterns has been a method of interest for recognizing early signs of communication delays or deficits, such as the lack of eye contact. Longer fixations and repetitive eye movements have also been linked with stereotyped, repetitive behaviors in ASD. Since eye tracking can be a useful tool in assessing differences in gaze patterns between infants at-risk with ASD and infants with typical development, the purpose of this study was to examine differences in gaze preference and fixation patterns between infants at high-risk for ASD (infants with a sibling diagnosed with ASD) and infants at low-risk for ASD (infants with no family history of ASD). Twenty-two infants at low-risk and eight infants at high-risk were examined longitudinally at three, six, nine, and 12 months of age. All infants were shown a preference paradigm displaying geometric and social images side-by-side while sitting on a parent's lap. Their gaze was measured using a FaceLAB eye tracker placed 60 cm in front of them. This setup allowed us to determine: 1) whether infants at high-risk spent less time fixating on social images and more time on geometric images compared to infants at low-risk, and 2) whether infants at high-risk for ASD exhibited shorter fixation durations than infants at low-risk regardless of stimulus type. Our results indicated that both groups of infants displayed a preference for social images at six, nine, and 12 months of age, on average spending 58% of their time looking at the social images and 25% at the geometric images. However, no preference for geometric or social images was observed at three months. This may be because the eye movement control of infants this young is not well-established by this age. Interestingly, both infant groups at three months tended to focus on the center of the screen rather than on either stimulus. In addition, the overall fixation durations for the infants at high-risk were significantly greater than infants at low-risk for ASD. Based on our preliminary results, fixation duration may be a potential quantitative measure that we can use to assess ASD in the first year of life. Utilizing a quantitative diagnostic tool for ASD could lead to an earlier and more reliable diagnosis, and it could also lead to earlier intervention for this population. More research on this topic is needed in infants before this conclusion can be confirmed.

Detriments in balance based on body mass index for patients with chronic obstructive pulmonary disease vs healthy adults.

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Introduction

Chronic obstructive pulmonary disease (COPD) is the third leading cause of death in the United States and worldwide. While COPD is defined in terms of fixed airflow limitation, it is also characterized by the frequent association of disease outside the lung, such as compromised balance potentially due to reduced muscle function and strength. Further, progression of COPD, including overall lung function, is affected by obesity. Obesity among adults in the United States increased from 30.5% in 1999-2000 to 37.7% in 2013-2014. The purpose of this study was to compare the effect of obesity, as defined by body mass index (BMI), on balance in patients with COPD compared to healthy individuals.

Methods

Ten subjects diagnosed with COPD (66.1±10.4yr; 170.1±5.6cm; 80.7±17.9kg) and 19 healthy subjects (59.7±9yr; 172.7±11.5cm; 79.2±18.7kg) agreed to participate. All subjects completed anthropometric measurements to determine BMI and completed a series of balance tests. BMI was calculated by dividing the subject's weight in kilograms by their height in meters squared (kg/m^2)^{11Okorodudu}. Ranges of BMI were used to classify subjects into four groups: underweight (< 18.50 kg/m^2), normal weight (18.50–24.99 kg/m^2), overweight (25.00–29.99 kg/m^2), and obese (> 30 kg/m^2). Balance tests included Sensory Organization Test (SOT) and the Motor Control Test (MCT) (NeuroCom® Balance Systems®). Data was checked for normality and analyzed using an ANOVA. A tukey post hoc test was used. The level of significance was set at an alpha level of <.05.

Results

A main effect of subject group (COPD vs Control) was found ($p < 0.001$), patients with COPD had worse balance on both tests. However, no difference in BMI, no matter the subject group, was found. A significant interaction was found between subject group and BMI (< 0.006). Healthy controls with normal, overweight, or obese BMI compared to patients with COPD and normal BMI were significantly had better balance for all tests ($p < 0.05$ for all comparisons). For the SOT composite score, there was significantly greater balance in healthy controls with obese BMI compared to patients with COPD and obese BMI ($p = 0.04$), healthy controls with normal BMI compared to patients with COPD and overweight BMI ($p = 0.045$), and healthy controls with normal BMI compared to patients with COPD and obese BMI ($p = 0.03$).

Conclusion

Patients with COPD were shown to have greater detriments in balance when compared to healthy controls regardless of BMI classification, affirming previous literature that patients with COPD have been shown to have decreases in balance. Interestingly, patients with COPD in the normal weight category show the greater deficits in balance compared to the overweight group, however it is important to note that the sample size for this weight category was considerably smaller than the overweight group. As BMI increases, composite scores of healthy controls showed decreases in balance as well. One considerable limitation of this study is the sample size, to further explain some of the detriments in balance it is important to increase the sample size, particularly for the COPD group.

Bowman, Lauren

The Effects of Optic Flow on Locomotor Symmetry

Walking seems to be an undemanding task; however, it requires a complex ability to adapt to changing environments. Our body relies on feedback from several sensory systems: visual, proprioceptive, and vestibular. When these systems conflict, the body relies primarily on visual feedback. Asymmetrical walking patterns, in both the spatial (i.e. step length) and temporal (i.e. step time) components may result from aging and disease. Learning how vision contributes to adapting to an asymmetrical walking pattern may prove useful in rehabilitating patients with asymmetric walking patterns. Twenty healthy, young adults participated in this study and were separated into two groups, virtual reality (VR) and non-virtual reality (NVR). Each subject had approximately 5% of their body weight attached to their left leg via an ankle weight and performed four treadmill trials: familiarization, baseline, limb loading, and wash out. A 3-way mixed model ANOVA was used for analysis and showed that optic flow did not produce a significant difference in the rate of adaptation to an asymmetrical walking pattern. However, unilateral limb loading affected both the spatial and temporal components. During late-adaptation, the spatial component returns to symmetry while the temporal component remained asymmetrical indicating that the temporal component was altered to maintain spatial symmetry. Removing the ankle weight reversed the direction of asymmetry. Limb loading affects symmetry differently for the temporal and spatial components; therefore, limb loading could be used during rehabilitation as long as precautions are taken to ensure that the temporal and spatial aspects of walking are being targeted correctly.

The Effects of Levodopa on Postural Complexity in Parkinson's Disease

Parkinson's Disease (PD) is associated with deleterious alterations to balance and postural control. Postural control is a prototypical example of a complex control system, i.e. the emerging result of continuously non-linear interactions between multiple physiological systems acting at different time scales. Research investigating postural complexity has demonstrated that aging and disease contribute to the deterioration of these systems, leading to over-simplification of postural control. This reduction in complexity results in a system being less adaptive and more susceptible to perturbations from the environment in which it is embedded, and in the case of posture, may lead to falls. Recent findings have evidenced that multifractal spectral (MFS) analysis of center of pressure (COP) displacement can provide insight into these nonlinear control processes involved in quiet standing by examining the MFS width. The width of MFS has been interpreted as a window into studying multiplicative cascading processes present in human behavior. These multiplicative interactions refer to couplings between scale-dependent variations across multiple scales that generate intermittent changes in measured behavior. Reductions in MFS width in quiet standing have been demonstrated in those with PD and liver disease. While MFS analysis has emerged as a promising tool to investigate postural complexity, it is still largely unknown how changes in postural strategy affect MFS. A recent experiment investigating the effects of "ON" and "OFF" states of Levodopa – an anti-parkinsonian medication - demonstrated changes in postural strategy employed by PD patients, moving from an ankle strategy to a hip strategy. Additionally multiple studies have recorded an increase in postural sway magnitude as a result of taking Levodopa, some authors concluding that this indicates a reduction in control. However, it remains to be determined how these changes in postural strategy and sway magnitude may relate to changes in postural complexity.

The purpose of this study is to examine progressive changes of postural complexity in PD patients due to the onset of Levodopa. **We hypothesize that Levodopa will enhance postural complexity and this enhancement will be correlated to changes in postural control strategies displayed by PD patients.** This will be achieved by measuring quiet standing (eyes open and eyes closed, randomized order) in 15 PD patients before taking their medication ('OFF' state), and every 20 min after taking medication, for 90 min, until full onset ('ON' state). Subjects will be instructed to stand quietly on a force platform for 60 seconds, while wearing a suit that allows the detection of specific kinematic markers. Those markers will be recorded with a motion capture system at 120 Hz, and the COP displacement will be recorded from the force platform at 120 Hz. Principal Component Analysis (PCA) of kinematic marker data will be used to quantify principal movements in subjects' strategies, providing a fine-grained analysis of how subjects' postural strategies contribute to COP variance. If confirmed, this finding will be the first to demonstrate the possible relationship between postural strategy and MFS complexity, and would provide significant import into the study of multiplicative cascades in human behavior.

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 characteristics 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.

METHODS

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 months 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 ≤ 0.05 was considered statistically significant for all comparisons.

RESULTS AND DISCUSSION

There were significant hand \times 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; $p = 0.11$].

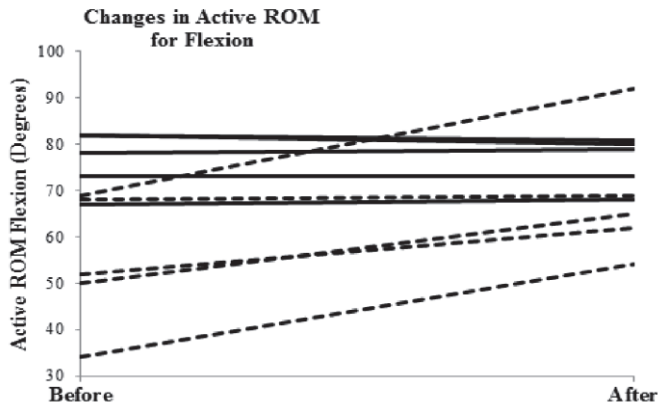


Figure 1. Shows individual changes for active range of motion (ROM) for wrist flexion before and after a 6 month period of using the low-cost 3D printed transitional prosthetic device.

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= $54.60 \pm 14.48^\circ$ and After= $68.40 \pm 14.29^\circ$), and active ROM extension (Before= $40.40 \pm 37.75^\circ$ and After= $47.00 \pm 36.42^\circ$ 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.

CONCLUSIONS

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 months 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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Individual Relationships between Locomotor Dexterity and Stride to Stride Dynamics

Austin Duncan and Vivien Marmelat PhD

The purpose of this study is to determine the relationship between stride to stride walking variability and an individual's walking dexterity. Dexterity is defined as the capacity to generate context-specific behaviors that align with the actor's goals. Dexterity of walking is readily observed when individuals must respond to being tripped. Highly dexterous individuals can account for the unexpected forces acting on their body and employ appropriate countermeasures to maintain stability. However, individuals with deficits in walking dexterity, such as older adults, are more likely to either avoid walking under challenging conditions, or to walk while experiencing higher risk of falls. Because falls are the result of a decrease in dexterity, measures of walking dexterity are enticing. However, much to the clinician's dismay, an individual's limit of walking dexterity can only be elicited under highly challenging circumstances and can only be precisely quantified using expensive motion capture equipment. Promisingly, recent studies of walking variability have provided insights for understanding walking dexterity. Walking variability refers to the spatiotemporal differences observed between consecutive strides. Both the magnitude and the patterning of stride-to-stride fluctuations provide insight into the neuromuscular control of the locomotion. Higher magnitudes of walking variability have been evidenced as a predictor for risk of falls and mobility decline for older adults⁴ and decreased walking variability patterning is displayed by fall prone elderly adults. In parallel, studies have evidenced a degradation of walking dexterity in older adults compared to younger adults. Therefore, walking variability has been proposed to reflect, to a certain extent, the degree of walking dexterity. Despite numerous studies finding that groups of older and pathological individuals exhibit changes in both walking variability and walking dexterity, the direct relationship between individual measures of walking dexterity and walking variability remains to be determined.

We hypothesize that individuals with a high magnitude of gait variability and a low level of gait variability patterning will perform poorly during a gait dexterity task in comparison to individuals with a low magnitude of gait variability and a high level of variability patterning.

A sample of 15 community ambulating older adults (age 65+) and 15 young adults (age 19-25) free of neurological disease and orthopaedic injury within the past year will be recruited to participate in this study. All data collection will be completed on a treadmill with the subjects wearing a safety harness. First, participants will walk on the treadmill at their self-selected preferred walking speed to become familiarized with treadmill walking. To analyze participants' walking variability we will instruct them to walk for 15-minutes with the treadmill set to their self-selected speed. Following a 10-minute break to minimize fatigue, participants will walk on the treadmill for an additional 15-minutes while being unexpectedly tripped 10 times. Participants' level of dexterity will be determined through kinematic and kinetic analysis of their trip responses.

Determining a strong relationship between walking variability and walking dexterity will both bridge the theoretical gap between these walking phenomena but also introduce gait variability measures as an integrated biomarker for gait dexterity allowing clinicians a highly efficient means of measuring their patients' gait dexterity and risk for falls.

Effect of task difficulty and visual condition on dual motor task performance in younger and older adults

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Background: Completing two concurrent tasks (dual task) is an inevitable situation in daily life. Dual task interference may destabilize the primary task, walking, increasing the risk of fall. Limited research investigating the effect of secondary motor task on walking has been done. Interference during dual motor task may be greater than during a dual cognitive task situation due to the use of similar brain networks. Further, interference during dual motor task performance can be influenced by external factors, such as vision. The aim of this study was to investigate the effect of levels of secondary motor task difficulty, as well as vision, on walking, during dual motor task conditions. A secondary aim was to examine the association between postural stability and locomotor stability, defined as step width mean.

Methods: Twenty-seven participants, including 15 younger (*aged* = 20.6 ± 1.96 yrs) and 12 older adults (*aged* = 70.42 ± 4.52 yrs) were recruited and after postural balance assessment (Neurocom sensory organization test), they were instructed to walk on a self-paced treadmill under the following conditions: (a) baseline; (b) clear tray (Less Difficult+Vision); (c) clear tray and glasses (More Difficult+Vision); (d) opaque tray (Less Difficult+Vision Obstruction); (e) opaque Tray and glasses (More Difficult+Vision Obstruction). Small glasses filled with water (1oz) were used to manipulate task difficulty and an opaque tray obstructed the vision. Mean and standard deviation values for (step length(SL), step width(SW), step time(ST)) were calculated. A 2×5 repeated measures ANOVA was used to compare means and variability between the conditions and groups. In addition, the Neurocom provided an equilibrium score that quantified postural stability during six sensory conditions. Less movement of the center of gravity (decreased sway) was given higher scores, indicating better postural stability. Pearson correlation was used to identify the relationship between equilibrium scores and step width mean for all conditions in two groups.

Results: Increasing the levels of secondary task difficulty, as well as obstructing vision, did not significantly alter SL, SW, and ST mean or variability between groups nor between conditions. There were negative, moderate correlations (R range: -0.43 to -0.64) between step width mean and equilibrium score for all conditions in only the younger adults. This relationship was not found in elderly population.

Conclusions: There were no differences in mean or variability of walking across conditions or between groups. The secondary motor task selected for this study may not have been challenging enough to cause an interference in walking. Further, standard deviation may be

less capable of discriminating gait variability changes than other more sensitive tools. There was no linear relationship between postural stability and locomotor stability in the elderly as compared to the presence of a correlation in the young. Suggesting that there may be particular factors that contribute to age-related changes in motor control causing this difference between age groups.

The effects of footwear outsole geometry on the biomechanics of walking using shoes with interchangeable outsoles

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Different groups have been studying the influence of shoe properties such as shoe weight and outsole geometry, hardness and stiffness on metabolic cost and biomechanics of gait. Most studies involve experiments where different types of shoes are compared that differ in more than one property. As a result, it is often not clear what is the isolated influence of each property. For example, it is not known what is the isolated influence of outsole inclination on the metabolic cost of uphill and downhill walking.

The purpose of this study is to identify a sole that is metabolically optimal for each inclination condition. In order to test one property, we will use shoes that allow interchangeable outsoles, while keeping the weight, hardness, and stiffness of the shoe and outsole constant. Based on the apparent use of devices that are used for mountaineering, like snowshoes or telemark skis, we expect that shoes with a higher heel will facilitate uphill walking and vice versa.

Twenty subjects from age 19-40 will be recruited and tested. The individuals will walk on a split-belt treadmill for 5 minutes for each condition. The subjects will be wearing reflective markers and they will also wear the Cosmed device to wireless collect metabolic data via indirect calorimetry.

What we hope to identify is an outsole that has a particular inclination and declination that is metabolically efficient at a 10% and -10% incline. This research could potentially be beneficial for an optimal footwear design for certain activities. For some activities, it could help design a shoe that had adaptive inclination, where you can attach a certain inclination for one activity and change it for another inclination for another activity. This research could potentially show an optimal design for flights of stairs so that they are more metabolically efficient to climb or descend from.

Theme of Research: Gait in young stroke survivors

Title: Asymmetry in the Complexity of Gait in Younger Stroke Populations: A Preliminary Study

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INTRODUCTION Stroke is a leading cause of disability and has historically been viewed as a pathology affecting the aged. However, there has been a significant increase recently in the prevalence amongst younger and middle-aged individuals. Nearly 795,000 Americans suffer from stroke each year and 25-45% occur in those younger than the age of 65. Regardless of age, a majority of stroke survivors walk with impairment, specifically, a deterioration in bilateral coordination leading to a loss of symmetry in temporal, spatial, or both domains. These asymmetries generate multiple issues including reduced speed and efficiency of walking, a reduction in loading, reduced dynamic balance stability, musculoskeletal imbalances leading to pain or injury, increased energy expenditure, and an overall decrease in activity levels. As a result, symmetric gait has been shown to be more efficient, and therefore targeting gait asymmetries has become a pertinent subject matter in stroke rehabilitation. Despite the differences in gait found to exist between healthy age groups, very little has been studied in varying age groups of stroke. **PURPOSE** The purpose of this ongoing study is to determine the impact of age on learning a novel gait paradigm post-stroke. **METHODOLOGY** Within the general chronic stroke population, twenty stroke survivors were assigned to one of two groups based upon age: Younger (21-60) and older (61+). All subjects completed a split-belt paradigm consisting of self-paced familiarization, baseline, early and late adaptation, stimulus removal and readaptation periods on an instrumented dual-belt treadmill. The paradigm was completed within a Virtual Reality (VR) environment in order to eliminate the visual-proprioceptive conflict treadmill walking alone creates. The VR environment was comprised of a corridor with optic flow matching the speed of the treadmill. The lab is fitted with an 8-camera motion capture system which allowed for full body three dimensional kinematics to be registered at 100 Hz. Marker locations were placed according to the full body Plug-In-Gait marker set allowing for spatio-temporal data to be captured as the subjects walked on the treadmill. **RESULTS** Using a split-belt paradigm intended to induce locomotor adaptation, spatio-temporal variables indicated differences between the way the younger and older groups learn the same novel gait task. **CONCLUSION** Prior to developing proficient rehabilitative strategies aimed at treating all stroke survivors, we must understand whether locomotion is impacted by age as has been demonstrated in healthy subjects. In order to do so, we must first understand how age impacts learning a novel gait task. The different approach to learning based upon age group found in this preliminary study is indicative that rehabilitative strategies employed should be further investigated based upon age of the stroke survivor. Subsequent to thorough investigation, will we then be able to adequately address unique characteristics of different ages of stroke survivors, and whether differing age groups should be rehabilitated in distinct manners to optimize functional improvement.

Biomechanics, Teaching

Software-Based Teaching of Biomechanics to Engage Undergraduate Students

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The purpose of this study was to determine whether software-based training can improve learning outcomes in Biomechanics. An existing biomechanics course was redesigned by integrating software-based training to compliment the lecture portion of the course. A questionnaire was handed to every student at the beginning of the semester. Open ended questions were answered by the students as well as questions based on Likert Scale. At the end of the semester, students were reevaluated with post-Likert scale questions to estimate student apprehension of the Biomechanics course. Post-semester results demonstrate that students are more confident in their understanding of Biomechanics, and that Visual 3D software positively influenced their learning. With the inclusion of software based training, our goal is to have students be better equipped to further seek career-paths in STEM following graduation.

Visual fractal metronomes influence stride-time variability

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Previous research has shown that humans are capable of implicitly synchronizing their movements to music or other rhythmic auditory stimuli. For individuals that are highly susceptible to falls, such as Parkinson's patients, stride synchronization to music has been used as therapy to improve gait and decrease fall risk. However, this form of therapy does not take into account natural gait variability, which is defined as the natural stride to stride fluctuations found in the gait of healthy individuals. It has been proposed that incorporating pink and brown noise into auditory stimuli may provide a structured, yet naturally variable metronome that better represents healthy gait. Visual metronomes provide another avenue for sensory motor synchronization, but previous work has shown less effective synchronization to visual stimuli. The majority of past studies have used discrete visual signals, where the patient takes a step each time a light flashes. Continuous, spatial metronomes (a moving light) are another form of visual stimuli for sensory-motor coupling. There is strong evidence that individuals presented with a continuous stimulus show a higher degree of visual-motor coupling than those treated with a discrete visual metronome.

The purpose of this study is to examine how synchronizing footsteps to continuous, visual metronomes with fractal structures affects stride time variability. Participants ($n = 2$) were asked to complete five, 15-minute walking trials. The initial trial was a baseline, where participants walked around a track at a self-selected pace. Mean and standard deviation of stride time from the baseline trial were used to create the stimuli for the test trials. Participants then completed four test trials, where they were asked to match their footsteps to continuous, visual metronomes. The metronomes consisted of a vertically moving bar displayed in front of a right lens of a pair of glasses. Participants were instructed to match the heels strikes of their right foot to the top of the moving bar's path and the heel strikes of their left foot the bottom of the bar's path. Participants walked to metronomes with white, pink, brown, and periodic (no-variability) variability structures for the test trials. Inter-stride intervals (ISI) of the participants walking and inter-beat intervals (IBI) of the metronome were calculated for all conditions. Mean, standard deviation, coefficient of variation, and detrended fluctuation analysis (DFA) α values were calculated for ISI and IBI time series.

Results suggest that the visual metronomes influenced participants' stride time. The difference between mean IBI and ISI was less than 0.01 seconds for all conditions, indicating that participants were able to successfully synchronize to the metronomes. Mean IBI DFA $\alpha = 0.51$ and mean ISI DFA $\alpha = 0.58$ when participants walked to the metronome with a white noise structure. When participants synchronized their gait to the pink noise metronome, mean IBI DFA $\alpha = 1.02$ and mean ISI DFA $\alpha = 0.84$. These results indicate that participants were able to synchronize their footsteps to the visual metronomes and that this visual-motor coupling influenced stride time variability. Additional participants are necessary to validate these results.

Effects of Dual Tasking on Auditory Selective Attention in Three Different Environments

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Performing attention-demanding tasks in a Virtual reality (VR) environment may show promise for improving fall prevention programming. Twenty healthy older adults (74 ± 9 years) completed a Dichotic Listening task with three auditory selective conditions: non-forced (NF), right forced (RF), and left forced (LF). Tasks were performed in a non-walking single task session (ST) and in both virtual reality (VR) and non-virtual reality (NVR) dual-task sessions on a self-paced treadmill. All individuals tested for normal hearing (20 dB) at low frequency (500) in both right and left ears, including the five that wore hearing aids. Repeated measures ANOVAs ($p < 0.05$) were used to examine condition (NF, RF, LF) and environment (ST, VR, NVR) comparisons with the right and left ear responses and spatial temporal gait parameters as dependent variables. Results showed right and left ear dichotic measures in the VR environment approached significance ($p = 0.057$) in comparison to the ST and NVR environments. Specifically in the VR condition, the FL condition approached significance ($p = 0.056$), for both right and left ear responses compared to the FR condition. Gait results showed a significant increase for double support time in the NVR compared to the VR environment ($p < 0.05$). Right step time in the VR environment also had a significant main effect ($p = 0.047$) while dual-tasking. These preliminary results suggest that a VR environment may positively influence dual-task performance, as both gait and cognition scores were better. Further investigation of dual tasking in a VR environment will strengthen methods and application of fall prevention programming for older adults.

Theme of Research: Locomotor Adaptation

The Effect of Bilateral Vestibular Stimulation on Locomotor Adaptation

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Locomotor adaptation requires input from vision, somatosensory and vestibular systems. The contribution of the vestibular system is important for maintaining postural control during gait, specifically the linear and angular orientation of the head on the trunk and acceleration feedback. Disrupting this system causes instabilities during locomotion. In previous studies, vestibular perturbation through caloric irrigation was shown to affect locomotor adaptation during slow walking. However, it is not clear how much the vestibular system contributes to gait adaptation. This study was done to determine if vestibular stimulation through bilateral mastoid vibration will affect gait coordination during the learning of a split belt task.

In this study, there was 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 years) did not receive any vestibular stimulation, while the other 9 subjects (22.3 ± 3.6 years) received vestibular stimulation, but all subjects 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 familiarization trial was then compared to the early adaptation split belt trial, late-adaptation split belt trial, and a second exposure split belt trial. The marker position data was used to determine the symmetry index for step length and step time, as well as the change in standard deviation in stride time for both right and left legs, were then analyzed.

While bilateral mastoid vibration did not disrupt the learning of the split belt task, those who had received vestibular perturbations had lower variability earlier in the trial when compared to later trials. The lower variability may indicate a restriction in gait pattern in order to allow sensory organization for learning the split-belt task, indicating that vestibular feedback is important for the early phase of learning. Its absence may restrict the explorative ability of the individual.

In conclusion, the individuals in the study were able to learn the locomotor task given, although a lack of the vestibular system restricted their explorative capabilities. In healthy subjects, sensory recalibration may reduce the effect of vestibular disruption during gait coordination training. However, in older adults or individuals with sensorimotor pathology, such recalibration may be difficult due to the risk of possible falls.

Title: Does short gait trials 'stitched' together provides the same information as longer trials in people with Parkinson's disease?

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Walking is characterized by slight changes from one step to the next, i.e. stride-to-stride fluctuations. The temporal ordering of these fluctuations provides significant insight about function and dysfunction of the locomotor system. For example, stride-to-stride fluctuations have been associated to the degree of functional impairment in patients with Parkinson's disease (PD). The analysis of stride-to-stride fluctuations requires a continuous recording of a large quantity of stride intervals, (e.g. participants walking for 15-30 minutes at a constant speed), which becomes a major limitation for populations such as elderly or PD patients. A potential solution to this limitation would be to 'stitch' together shorter gait trials (i.e., to combine five separate three minute trials into one fifteen minutes trial). The aim of this study is 1) to determine if 'stitching' shorter gait trials to create one longer series of stride intervals will provide similar stride-to-stride fluctuations compared to one continuous long gait trial, and 2) to determine if the stitching procedure affects similarly healthy and pathological populations.

15 healthy young adults (HY group, 23.00 ± 1.75 years old), 15 healthy elderly (HE groups, 68.21 ± 6.89 years old), and 13 PD patients (PD group, 71.08 ± 6.32 years old) participated in the study. PD patients data were collected while being 'on' medication. The study consisted of 45 total minutes of walking, divided in three different trial sections. Each trial section lasted 15 minutes and were defined as '15min' (1 trial of 15 min walking without interruption), '3min' (5 trials of 3 min with 1 min rest between trials) and '30sec' (30 trials of 30 sec with 30 sec rest between trials). At least 5 min rest was provided between conditions. Force-sensitive footswitches placed under participants heels and toes were used to detect gait events (heel strikes and toe off). Time series of stride time intervals were then generated from the difference between the timing of two consecutive events from the same foot. Stride-to-stride fluctuations were estimated with the detrended fluctuations analysis, which provides the scaling exponent α -DFA. A two-way ANOVA (3 groups X 3 conditions) was used for comparisons, and Intra-Class Correlation analysis was performed between the three conditions for each group to determine the reliability of the scaling exponent.

ANOVA revealed no statistical significant effect of group ($p=0.1278$), conditions ($p=0.4411$) or interaction between them ($p=0.5873$) on the scaling exponent α -DFA. Our results evidenced that in the '15min' condition, PD patients walked with greater CV (non-statistically significant differences, $p=0.0752$), and with lower α -DFA values (non-statistically significant differences, $p=0.3416$). More precisely, α -DFA values were equal to 0.84 ± 0.1283 , 0.8915 ± 0.1520 and 0.9169 ± 0.0712 for PD, HE and HY, respectively. The ICC revealed Cronbach's alpha equal to 0.8524 ($p<0.001$), 0.7225 ($p<0.01$) and 0.4977 ($p=0.0588$) for PD, HE and HY, respectively.

Our results suggest that 1) stride-to-stride fluctuations were similar between the three groups, in the three conditions, and 2) stride-to-stride fluctuations obtained from the 'stitching' procedure were consistent with those obtained during longer walking trials, in particular for the HE and PD groups. It is surprising that PD patients did not present a decrease in the scaling exponent α -DFA as previously reported in the literature. This may be due to a combination of factors, such as having PD patients in early stage of the disease (Hoehn & Yahr scale = 1.58 ± 0.67), or having a larger quantity of stride intervals than previously reported (>500 strides, while previous studies reported 50 to 200 strides). If confirmed with larger sample and different pathological groups, our results could allow the investigation of neuromuscular control of locomotion in populations that were previously unable to be extensively studied.

POSTURAL CONTROL MECHANISMS MAY BE PRESERVED DESPITE SENSORY DEFICITS FOLLOWING UNILATERAL TRANSTIBIAL AMPUTATION

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The ability to stand is requisite for performing many activities of daily living. During quiet standing the manner in which the center of pressure (COP) of the body moves over time can reveal the underlying processes that control the movement.

Postural sway can be characterized according to its velocity patterns. Sway may be described to exhibit ‘persistence’ when a COP velocity change in one direction is more likely to be followed by a change in the same direction. Conversely, it may exhibit ‘anti-persistence’; a change in one direction is more likely to be followed by a change in the opposite direction. Intriguingly, sway patterns of healthy young adults demonstrate both persistent and anti-persistent behavior, but at different timescales [1]. When examining the patterns within small time increments (e.g. within 1 second) the fluctuations are persistent, whereas at longer time scales (i.e. over several seconds) the fluctuations are anti-persistent. It has been postulated that this transition from persistence to anti-persistence reflects the action of a control mechanism that evokes a directional change when a threshold of velocity is exceeded [1].

Given that cutaneous receptors beneath the foot are ideally positioned to detect these movements, it is possible that their sensory contributions play a direct role in the mediation of this velocity-based control mechanism. This premise was tested by comparing the COP velocity patterns of adults with no impairments to a group of individuals with a transtibial amputation who, by virtue of their surgery, have an asymmetric sensory deficit. We hypothesized that, due to this sensory loss, amputees would exhibit less short term persistence and less long term anti-persistence, i.e. a convergence towards similar dynamics at both timescales.

Eleven individuals with a unilateral transtibial amputation (60.2±15.9 yrs, 1.8±0.1 m, 98.8± 13.7kg) and seven unimpaired individuals (40.6±9.7 yrs, 1.7±0.1 m, 85.3±24.3 kg) consented to participate. Participants stood for 90 s on parallel force plates (Optima, AMTI, Watertown, MA), with their feet ‘as close together as possible’ and arms crossed in front of their torso. COP trajectories at 60 Hz were low-pass filtered at 10 Hz and differenced to obtain COP_v.

Detrended fluctuation analysis (DFA [2]) was used to quantify persistence in COP_v in anterior-posterior (AP) and medial-lateral (ML) directions. From DFA, $\alpha > 0.5$ reflects persistent fluctuations while $\alpha < 0.5$ reflects anti-persistent fluctuations, and $\alpha = 0.5$ indicates randomness. Persistence was quantified over approximately 0.2-0.6 seconds (α_{short}) and 1.8-11.3 seconds (α_{long}). Group differences between individuals with and without an amputation were determined using Welch’s t-tests for unequal variances in R (R core team, Vienna, Austria).

In partial support of our hypothesis, in the AP direction the participants with transtibial amputation exhibited less persistent sway patterns at the short timescale in comparison to controls ($\alpha_{\text{short}} = 1.2 \pm 0.2$ vs 1.4 ± 0.1 , $p = 0.04$). However, increased antipersistence was observed at long timescales ($\alpha_{\text{long}} = 0.2 \pm 0.1$ vs 0.4 ± 0.1 , $p = 0.01$). There was no difference between groups in the ML direction (α_{short} : $p = 0.36$; α_{long} : $p = 0.53$). Although group differences were observed in the AP direction, the marked disparity between short term persistence and long term anti-persistence remained evident in both AP and ML directions of the individuals with amputation, potentially indicating similar velocity-based control. The lack of a group difference in the ML direction was surprising given the absence of cutaneous plantar sensation from half of the base of the support in prosthesis users.

Our results indicate that cutaneous plantar sensation may only play a minor role in the preservation of the short-term and long-term behavior of the COP velocity during quiet standing. Alternatively, the residual limb may be able to take on a greater sensory role than we anticipated.

Theme of Research: Cognitive/Motor Dual-Task

Title: Effects of Serial Subtractions on Elderly Gait Speed in a Virtual Reality Setting

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Falls are the leading cause of fatal injuries in older adults aged 65+ with one in three adults falling each year. Cognitive processes are involved in gait, and thus, as cognitive changes are normative with age, this may impact fall risk in the elderly. The purpose of this study was to investigate the effect of a serial subtraction task on elderly gait. Sixteen older adults aged 70.8 ± 5.3 years took part in a dual-task (DT) study where they walked on a split-belt self-paced treadmill with and without a virtual reality (VR) setting while simultaneously performing a serial subtraction (SS) task. For SS, individuals were given a random 3-digit starting number and told to subtract by three from that number for one minute; this process occurred three times. Only correct substitutions were counted toward their total score. Previous literature has shown that individuals will slow their gait to deal with a cognitive task, and our results supported this trend. Subjects tended to walk slower in both the VR and non-VR settings while dual-tasking compared with the walking-only control trial; walking while SS was significantly slower in the NVR session ($p = .024$) and more variable ($p = .048$). Initial analyses found no significant differences in correct scores between conditions, however, when grouping based on age and gender, there was a significant difference ($p < .001$ and $p = .003$). Subjects 71 years (young-old) and below performed better in the SS task (67 correct) compared to subjects 71 years (old-old) and older (35 correct). Males scored better (64 correct) when compared to females (44 correct). However, the gender differences could be due to the fact that there are more females than males in this study, with a greater amount of females being in the 71 and older group. Overall, DT increased SS performance in young-old while there was no change in old-old. These results may suggest that dual-task training could improve cognitive function in some older adults. Some older adults may prioritize one task over the other, i.e. decreasing motor function to deal with a cognitive function and vice versa. While most of the older adults walked slower while dual-tasking, they were still able to complete the task which could suggest that serial subtraction is not difficult enough to seriously perturb gait. Future studies could increase task difficulty to investigate how much gait could be disturbed to make a significant impact to induce and/or predict falls.

EFFECT OF SLOPE AND SPEED ON KINETICS OF JOGGING WITH A BACKPACK

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INTRODUCTION

Running while carrying a load under different conditions such as slopes and speeds is a part of military training [1], trail running [2], commuting and conditioning exercises [3]. There have been different studies on effects of slope [4–6], speed [7,8] and load [3,9,10] on biomechanics of running. However, only a limited number of studies analyzed the effects of multiple parameters in interaction (e.g. [3]) and, to the best of our knowledge, there has been no study on the effects of slope and speed during jogging with a relevant military load at slow speeds that are likely to occur at such slope and load combinations. Knowledge about the effects of slope and speed on the joint kinetics can be useful for understanding the performance requirements of different types of terrain and for preparing accordingly. Our aim is to study the effects of slope and speed on joint kinetics during slow jogging with a military relevant backpack load. We hypothesize that uphill jogging will increase positive work (mostly at the hip and ankle) [5, 6] and reduce negative work and that faster jogging will increase both positive and negative work (mostly at the hip and ankle) [3,7,8].

METHODS

We tested 10 healthy male participants (29 ± 2 yrs; 76 ± 3 kg; 1.79 ± 0.02 m; mean \pm s.e.m.) during jogging on a treadmill (Bertec) at 15 combinations of slope (-8 , -4 , 0 , $+4$ and $+8^\circ$) and speed (2 , 2.5 and 3 m s⁻¹) with a 15kg backpack. We measured joint kinetics using motion capture (Vicon). We calculated rates of positive and negative work for each joint by integrating positive and negative

power portions and dividing by stride time. Next, we evaluated the linear, second order and interaction effects of slope and speed on each metric using mixed-model ANOVA with stepwise elimination.

RESULTS AND DISCUSSION

As hypothesized, we found that an increase in slope leads to an increase in positive work rate at the hip and ankle joint (similar to [5] and [6]) and to a decrease in negative work rate mostly at the knee joint and for the sum of all joints (Figure 1). Furthermore, we found that an increase in speed led to an increase in positive work rate at all joints, but at the knee this effect is very small. We also found that an increase in speed led to an increase in negative work rate for all joints. We found significant interactions for the effect of slope and speed in all joints for positive work rate but only in the knee for negative work rate (Table 1).

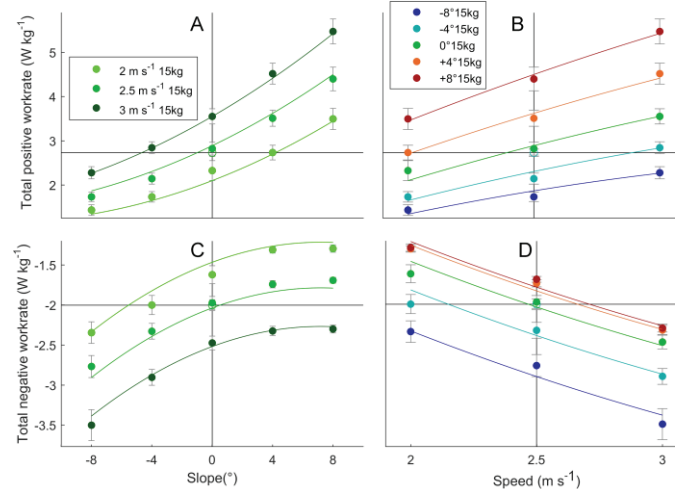


Figure 1: Effects of speed (a,c) and slope (b,d) on total positive (a,b) and negative (c,d) work from the hip knee and ankle. Dots and error bars are mean \pm s.e.m. Lines show curve fits from ANOVA.

CONCLUSIONS

These results quantitatively show that fast uphill loaded jogging is strenuous, not only because positive joint work rate increases with slope and speed, but also because the interaction between slope and speed further magnifies these effects. Results also show that the combination of fast downhill jogging leads to high negative work at the knee because of the effect of slope, the effect of speed and that this is further magnified by interaction of slope and speed. Knowledge of these effects can be useful for choosing pacing strategies, course selection, estimating injury risk, optimizing training and rehabilitation and for selecting and developing orthotic or assistive devices. For example, an assistive exoskeleton for running [11] could be programmed to change its assistance magnitude based on the equations in table 1 to mimic human responses to changes in slope and speed.

ACKNOWLEDGMENTS

This work was funded by Defense Advanced Research Projects Agency (DARPA), Warrior Web Program (Contract No. W911NF-14-C-0051), NSF (Grant No. CNS-1446464), Wyss Institute, John A. Paulson School of Engineering and Applied Sciences at Harvard University. We thank Adham Meguid, Andrew Long, Asa Eckert-Erdheim and Lauren Baker for their help.

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Table 1: Coefficients of mixed-model ANOVA for each outcome metric. Only significant terms were retained (p-values < 0.05). Outcome metric = intercept + a · slope + b · slope² + c · speed + d · speed² + e · (speed · slope) with slope in ° and speed in m s⁻¹.

	Intercept	a (slope)	b (slope ²)	c (speed)	d (speed ²)	e (speed · slope)	R ²
Positive hip work rate (W kg ⁻¹)	0.518		0.004	-0.409	0.237	0.034	0.946
Positive knee work rate (W kg ⁻¹)	-0.684		0.001	0.891	-0.163	0.007	0.689
Positive ankle work rate (W kg ⁻¹)	-2.195			2.248	-0.330	0.026	0.913
Negative hip work rate (W kg ⁻¹)	-0.022	0.005	-0.001		-0.022		0.587
Negative knee work rate (W kg ⁻¹)	0.333	0.029	-0.003	-0.572		0.009	0.901
Negative ankle work rate (W kg ⁻¹)	1.293	0.014	-0.001	-1.273	0.178		0.883
Total positive work rate (W kg ⁻¹)	-2.341		0.005	2.731	-0.256	0.066	0.953
Total negative work rate (W kg ⁻¹)	1.700	0.070	-0.005	-1.938	0.177		0.929

Variability of activity behavior from activity monitoring across seven days.

Katlyn Nimtz, Nicholas Reynolds, Vivien Marmelat, Brian A. Knarr

Recent studies show that measures of walking performance can be a predictor of disability in older adults. Older adults who have been diagnosed with osteoarthritis (OA) participate in less activity, indicated by the poor mobility associated with weight bearing pain. Of the 700,000 TKAs performed annually, 50% require contralateral TKA within 10 years. Activity monitoring is a common way of measuring daily activity. Results from activity monitors can also provide information about the individual's healthy functional outcomes. In addition to total amount of activity, the daily structure of activity from day to day provides insight into an individual's behavior. It is possible that individuals with more regularity in their daily activity may be more likely to maintain a more active lifestyle compared to those who are inconsistent in their daily routine. In this study, we will determine the difference between epoch sizes and Jensen-Shannon Divergence (JSD) in healthy elderly (HE). We hypothesize that there will be a similarity between standard deviation of steps and Jensen-Shannon Divergence, but there will be no similarity in the total number of steps compared to Jensen-Shannon Divergence from activity data. Twenty-eight healthy older adults (65.15 years; 9 males and 18 females) wore an activity monitor on their non-dominant wrist for seven consecutive days. They were instructed to continue with their normal daily activities. Data was extracted in 15sec intervals from the step count series. Jensen-Shannon Divergence takes a comparison between two individual days and compares them to the average of all total days. Results show a self-similarity between all total days. The lower an individual's JSD value, the more consistent their behaviors are between all 7 days. Greater values indicate less similarity between activity days. JSD was run in 15sec, 30sec, 1min, 10min, 30min and 60min epoch intervals. The results show that at higher interval epoch sizes the activity structure is less similar, while at smaller epoch sizes, activity structures are more similar. R-squared values were calculated to show the similarity between JSD versus standard deviation and JSD versus total number of steps. While epoch size is increasing, the r-squared values for mean daily steps are shown to be decreasing (0.571, 0.502, 0.440, 0.299, 0.202, 0.131). However, the opposite is occurring for standard deviation of daily steps. While the epoch size is increasing, the r-squared values are increasing (0.070, 0.081, 0.089, 0.107, 0.122, 0.161). Overall, smaller epoch sizes could potentially be used to analyze activity data from activity monitors to establish a more accurate analysis. Interestingly, only mean total steps showed a meaningful relationship with JSD value, with epoch sizes 1 min or less showing r-squared values greater than 0.440. While greater standard deviation values would suggest difference in day to day behavior, similarity of activity patterns were not related to standard deviation. Overall, our results indicate that older adults who are more active may be more consistent their daily activity patterns than those who do not.

Theme of Research

Orthopedic Biomechanics-Knee Osteoarthritis

Title

Stride width predicts knee flexion moment asymmetry post total knee arthroplasty

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Body: You will have to copy and paste your abstract into the registration page. The body of the abstract should be organized as follows:

A sentence stating the study's purpose

A brief description of methods

A summary of the results

A statement of conclusions reached. Do not state simply the "the results will be discussed"

Body: Total knee arthroplasty (TKA) is the most common surgical procedure to overcome end-stage osteoarthritis (OA) in the knee joint. In the US, more than 700,000 TKA surgeries are performed annually, to which 97% of those due to OA [1]. Within 10 years of the primary TKA, almost 50% of patients undergo a secondary TKA on the contralateral limb due to OA progression [2]. Individuals with end-stage knee OA exhibit asymmetric knee joint loading. This asymmetry is believed to compensate for pain and weakness in the affected limb [3]. While TKA effectively relieves knee joint pain, asymmetric kinematics/kinetics persist post-operation [4]. It is thought that by shifting more load on the non-surgical limb, the chances of contralateral OA may increase [5]. However, it is difficult to assess loading in clinical settings as the needed equipment can be prohibitively expensive. Thus, the purpose of this study was to investigate if spatial temporal measurements predict inter-limb loading asymmetry during walking in patients after TKA. We hypothesize that spatial-temporal asymmetry will be positively correlated with loading asymmetry post-TKA.

Sixteen individuals after TKA participated in this study (age 68 ± 6.1 years, BMI 28.8 ± 4.6 kg/m², Post-TKA 11.5 ± 6.5 months). Data were collected using an instrumented split-belt treadmill (Bertec Corp. Columbus, OH) and an 8-camera motion capture system (Motion Analysis Corp. Santa Rosa, CA). Kinematic data were sampled at 100 Hz and the force data were sampled at 2000 Hz. Subjects performed the 6-meter walk test to determine self-selected (SS) and fast speeds. One-minute walking trials for each speed (SS & fast) were recorded. The kinetic and kinematic data were analyzed using Visual 3D (C-Motion Inc. Germantown, MD). Pearson correlation coefficients were calculated using SPSS Statistics (SPSS Inc, IBM Corporation). Inter-limb symmetry ratios were defined as percentage of Sx/noSx value. Values above 100% indicate greater loading values on the surgical limb. VGRF values were normalized based on body weight (N/BW). Knee moments values were normalized on body weight multiplied by height (N/BW*HT).

Stride width showed a significant correlation with knee flexion moment symmetry ($r^2=0.53$, $P<0.001$) during fast walking trials. Subjects demonstrated inter-limb loading asymmetry post-TKA, but the direction of asymmetry varied between subjects. Within limbs, results showed correlations between stride length and 1st peak VGRF during self-selected (Sx $r^2= 0.49$, NSx $r^2=0.48$) and fast (Sx $r^2=0.73$, NSx $r^2=0.46$) walking, but no significant correlation was recorded between symmetry indices during self-selected and fast walking. This indicates that as stride/step length increases, first peak vertical ground reaction forces increase, but these measurements do not adequately describe VGRF asymmetry post-TKA (Figure 2). No additional correlations were found between spatial-temporal (stride length, step length, step time) and loading (1&2 peak VGRF, knee flexion moment, and knee adduction moment) symmetry indices.

A significant correlation between stride width and knee flexion moment symmetry index was found, though no other significant correlation between spatiotemporal and loading symmetry indices at either self-selected or fast walking speeds was recorded post-TKA. Future work should examine the mechanisms related to stride width and loading in a TKA population, as well as exploring individual step width in relation to center of mass. Overall, however, these findings indicate that clinically accessible methods to assess joint loading are needed to assess interlimb loading asymmetry in post-TKA patients, as simple spatiotemporal measures may not provide proper insight into loading asymmetry.

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CAN FOOT MECHANICAL ENERGY BE DISSIPATED AS HEAT?

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INTRODUCTION

The human foot contains elastic structures (e.g., plantar fascia) that can store and return mechanical energy [1]. Such structures are thought to play a role in reducing the metabolic energy demands during locomotion [2]. Yet, when accounting for all structures within the foot (e.g., muscles, tendons, and soft tissue deformation), the human foot appears to perform net negative work during walking [3]. It is unclear how the body utilizes this net negative work; specifically, whether this energy is used to supplement the body's movement.

There are several possibilities regarding the destination of the foot's net negative work. One possibility is that the foot's energy is transferred proximally through multi-articular muscles (e.g., flexor digitorum or hallucis longus); yet, only a small portion of the foot's energy appears to be transferred through these muscles [4]. Other possibilities may be that the foot's energy dissipates in the form of sound or heat. In fact, walking can induce increases in foot temperature [5], and thus heat transfer may be a plausible outcome for the foot's net negative work.

The purpose of this study was to investigate the link between foot mechanics and temperature regulation. We aimed to increase foot's net negative work by adding mass to the body during walking. We hypothesized that the magnitude of the foot's net negative work would correlate with increased foot temperature during walking with added mass.

METHODS

One subject (age = 33 yrs, height = 1.74 m, mass = 67.2 kg) completed barefoot walking trials over-ground and on a treadmill, both with and without added body mass. Added mass conditions included 15% body mass and 30% body mass added via a vest that distributed the mass equally around the core. The order of the three sessions (0, 15%, and 30% added mass) was randomized.

First, baseline temperature recordings were taken at three different sites on the plantar surface of the foot (heel pad, 1st and 5th metatarsal heads), dorsal surface at the 1st metatarsal head, shank (~50% distance between knee and ankle joints), and thigh (~50% distance between hip and knee joints). Then the subject walked over a force plate targeted at 1.25 m/s. After the foot returned to baseline temperature, the subject walked on a treadmill for 10 minutes. Foot, shank, and thigh temperature were recorded after the treadmill trial.

The mechanical power of the foot during the over-ground trials was quantified using a unified deformable segment analysis [6], by modeling all structures distal to the calcaneus as a deforming body [3]. Positive and negative work were quantified by

integrating the power with respect to time. The net work was compared with the changes in temperature.

RESULTS AND DISCUSSION

When the subject walked with added mass, the magnitude of the foot's positive work remained relatively similar. However, the magnitude of negative work increased, and thus the magnitude of net negative work increased; most notably between the 0% and 15% added mass conditions (Figure 1).

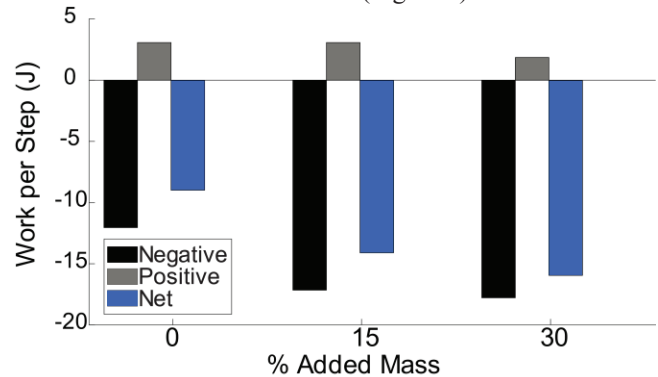


Figure 1. With added mass, there was an increase in foot negative work (black), small change in positive work (grey), and an increase in magnitude of net negative work (blue).

After 10 minutes of treadmill walking without added mass, temperatures increased at all sites (Table 1). Temperature increased most notably at the foot, with smaller changes occurring at the shank and thigh. Specifically, the greatest temperature changes occurred at the plantar surface (under the 1st and 5th metatarsal heads and the heel pad). Walking with added mass magnified this temperature increase, again most notably at the plantar surface, and most drastically at 30% added mass (Figure 2).

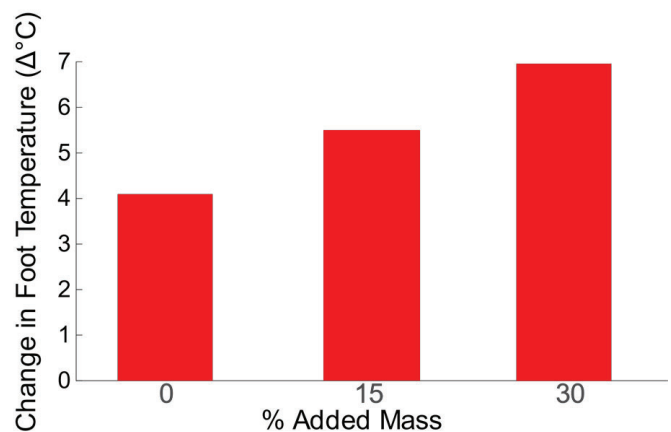


Figure 2. During 10 minutes of treadmill walking, the average temperature of the plantar surface increased with added mass.

As the magnitude of foot net negative work increased with added mass, the average temperature of the plantar surface also increased (Figure 3).

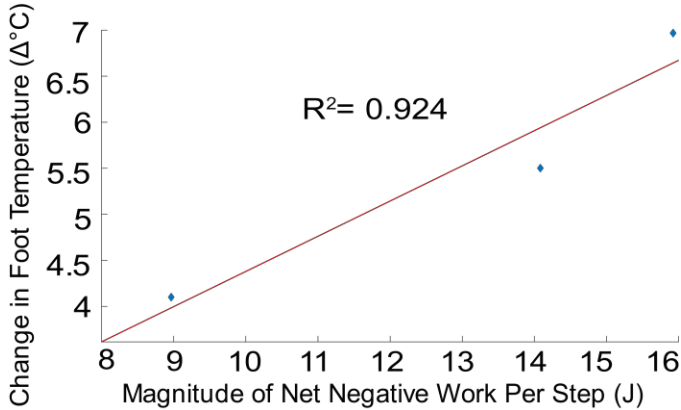


Figure 3. The magnitude of net negative worked per step (during over-ground walking) was positively correlated with an increase in average temperature of the plantar surface (during 10 minutes of treadmill walking).

CONCLUSIONS

These preliminary results support our overall hypothesis that net negative work at the foot may be dissipated as heat. Currently, our analyses cannot parse out the exact source of heat production, such as shear force [5], soft tissue deformation, or muscle force generation. Determining such contributions is expected to give new insights into the mechanism of impaired temperature regulation, such as in patients with diabetes who are prone to ulcer formation in the foot [7].

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Table 1: Temperature measurements after 10 minutes of treadmill walking with added mass.

Temperature (°C)	Plantar Surface of the Foot			Other Areas		
	Heel Pad	1 st Met Head	5 th Met Head	1 st Met Head (Dorsal)	Shank	Thigh
Baseline	21.7	21.0	20.9	21.8	28.6	30.0
0% Added Mass	26.0	25.0	24.9	23.6	29.4	31.0
15% Added Mass	27.1	26.5	26.5	24.0	29.8	31.0
30% Added Mass	29.5	28.0	27.0	24.9	30.8	31.2

Does the Continuity between the Achilles Tendon and the Plantar Fascia Influence Foot and Ankle Power Production

There is an anatomical continuity between the Achilles Tendon (AT) and the plantar fascia (PF), but this continuity deteriorates with aging. This deterioration has implications for the transfer of energy and force between the AT and PF, and may contribute to the age-related loss in foot and ankle power production in older adults. The purpose of this study is to determine whether the AT-PF continuity influences foot and ankle power production in-vivo in young and older adults. We will use ultrasound to measure displacement of the AT when extending the hallux, and displacement of the PF when selectively activating the gastrocnemii muscles. It is hypothesized that older adults will have a decreased AT-PF continuity compared to young adults, and that degraded continuity will be correlated with reduced foot and ankle power production during walking.

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. The Centers for Disease Control and Prevention estimates that about 1,500 babies are born with upper limb reductions every year, and of these only 1 in 9,400 children is considered for prosthetic fitting. This disparity between instances of amputation/reduction and prosthesis prescription is a result of high cost and complex needs, due to children's small size, constant growth, and psychosocial development [1, 2].

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 [1, 2].

Advancements in computer-aided design (CAD) programs and additive manufacturing offer the possibility of designing and manufacturing prostheses at a very low cost [2]. 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.

METHODS

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 AND DISCUSSION

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).

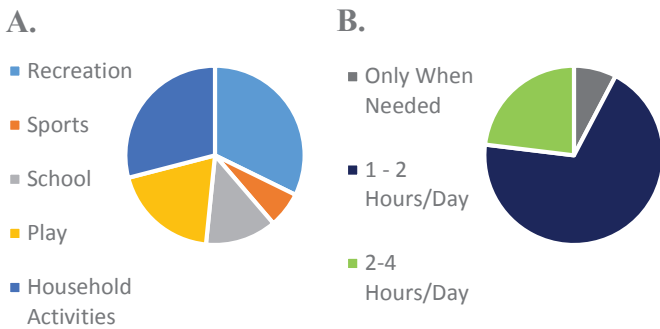


Figure 1: Qualitative usage metrics for 3D printed prostheses. A: Activity Type; B: Daily Hours Used

Four children reported malfunctioning and/or breaking of the 3D printed prosthetic device.

The main finding of our survey was that our 3D printed transitional prostheses have a great potential to 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 more durable, medical grade 3D printed prosthetic devices to solve these durability constraints.

The proposed solution to this issue is a stepwise improvement of the prosthesis design through user feedback. The relative speed at which modifications can be performed through the use of CAD and 3D printing allows for many iterations of a design to be produced, fitted and evaluated over the course of weeks, rather than months, or years, as with traditional prostheses. [1]

Unfortunately, some observed inaccuracies with collected survey results have been noted in related studies, and a more quantitative method for determining usage is desired. This would allow for more informed future design modifications and more downstream functionality.

A prototype of an appropriate quantitative test apparatus for usage has been constructed, and will be validated in future studies.

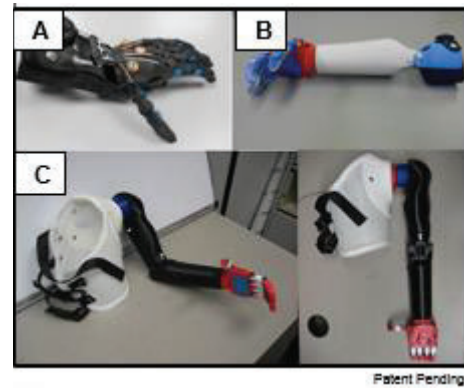


Figure 2: Shows some of the 3D printed transitional prostheses prototypes developed by our research team. A: Hand prosthesis (Cyborg Beast); B: Below Elbow Device; C: Prosthetic Shoulder.

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. The technology opens up the possibility to help clinicians working in rehabilitation to establish guidelines for prosthesis prescription, establish effective rehabilitation programs, and create new prosthetic designs with the ultimate goal of improving self-esteem and quality of life for children with upper-limb reductions.

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.

3D printed transitional prostheses have a great potential to positively impact quality of life, daily usage, and can be incorporated in several activities at home and in school.

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Temporal correlations of support surface movement affect the control of center of pressure velocity

Interacting with changing environments is a key feature of postural control. Being able to maintain posture under a variety of environmental constraints is a sign of adaptability. The postural response to support surface movements provides insight into postural adaptation. Therefore, the purpose of this research was to investigate the postural response to support surface translations that contained different strengths of temporal correlations, as well as different average movement velocities.

Twenty participants stood on the Neurocom balance manager while the support surface was translated in the anteroposterior direction with no temporal correlation (white noise), moderate temporal correlation (pink noise), and near perfect temporal correlations (sine wave). The support surface was translated at five different movement velocities (0.5, 1, 2, 3, and 4 cm/s) for each waveform. Center of pressure velocity (COP_{vel}) was recorded and analyzed using a modified DFA algorithm. This method determined two properties of temporal correlation, the inflection point and short term persistence. A log/log plot was generated of the root mean square fluctuation as a function of time scale, then the inflection point and linear short-term region were selected. The inflection point indicates at what time scale the COP_{vel} switches from a persistent to an anti-persistent behavior, and the short-term region indicates the strength of persistence in the region preceding the inflection point. A two way repeated measures ANOVA was compared the average movement velocity and temporal correlations. A Dunnet's test compared each movement trial to baseline standing.

The two-way ANOVA for inflection point showed no effect of movement velocity ($P = .98$) but there was an effect for temporal correlations ($P < .001$). The inflection point in response to the sine wave movement remained longer than in response to the white or pink noise movement, across all movement velocities. When comparing to baseline standing the Dunnet's test was significant ($P < .001$), showing reduced time to inflection in response to white and pink noise and increased time to inflection in response to the sine wave at all movement velocities 2 cm/s and above. The two-way ANOVA for short-term persistence showed an effect of movement velocity and temporal correlations ($P < .001$ for both). The short-term persistence was strongest in response to the sine wave movement and weakest in response to the white noise movement in all movement velocities 1 cm/s and above. When comparing to baseline standing the Dunnet's test was significant ($P < .001$) mostly at 4 cm/s, where the response to white and pink noise had weaker temporal correlations and the response to the sine wave had stronger correlations.

The increased time between COP_{vel} oscillations in response to the sine wave movements could indicate a feedforward response, where the predictability of the movement allows the central nervous system to estimate how much the COP_{vel} can increase and decrease while still safely interacting with the moving environment. In response to the white and pink noise movements the system must rely on feedback, due to the unpredictability of the signal. The short-term persistence in response to the sine wave movement supports the hypothesis of a feedforward response, it is notable that a couple of movement velocities resulted in a weaker short-term persistence in response to white noise compared to pink noise movements. This indicates that the stronger correlation of the pink noise signal may allow the system maintain a stronger correlation within COP_{vel} increases and decreases. This information could be useful in both diagnostic and rehabilitative settings. From a diagnostic standpoint, protocols could be designed to assess one's ability to use feedforward or feedback processes to maintain balance. From a rehabilitative standpoint, protocols could be designed to train feedforward or feedback processes during posture.

A correlation Network Model Utilizing Gait Parameters for Evaluating Individuals' Health Levels

Abstract

Healthcare is moving rapidly from the long-standing reactive treatment approach to the early detection and preventative era. However, to fully embrace this trend, new paradigms need to be adopted and new approaches need to be developed. A step in this direction is to explore how to leverage data collected from wearables sensors and other mobility-related devices to help in assessing health levels. This would pave the way for continuously monitoring individuals, which, in turn, lead to helping physicians diagnose diseases in the early stages. Although progress in sensor technologies has given rise to the possibility of implementing this approach, the lack of a sophisticated data analytics model remains a major missing piece in moving forward with this concept. In this study, we propose a new correlation network model in which several aspects associated with health levels can be identified using population analysis. Many aspects of health-related assessments are based on comparing individual's data points with as many data points as possible in related populations. Clinical diagnosis and treatment evaluation would be very difficult without population comparisons. Therefore, in constructing the proposed correlation network model, there is an absolute need of having access to the gait parameters and other related parameters from different populations. The proposed model is based on identifying various distinguishing mobility parameters associated with groups under study. Variability of gait, stride length, stride time, cadence, and asymmetry are some of the gait parameters that have been studied in the context of clinical decision making. These gait parameters should be selected carefully to be used in creating an accurate correlation network model. Then a correlation network is developed based on the specified parameters. In such network, each node corresponds to a person and two nodes are connected by an edge if the corresponding individuals share similar mobility profiles. We show that useful information can be extracted from the constructed network and that various network properties such as clusters, cliques, and gateways, reflect health information of the groups under study. To test the proposed model, we use mobility data collected from three various groups, healthy younger people, geriatrics and Patients with Parkinson's Disease. Gait parameters, including average stride time, average vector magnitude of acceleration, stride time variability, vector magnitude symmetry and some other parameters are extracted. These gait parameters are taken to the correlation analysis step if they are significantly different at least between two populations under the study. Results of ANOVA and Post-hoc tests show that average stride time of healthy control group is significantly less than that of the geriatrics, while it is higher in geriatrics compared to patients with Parkinson's Disease. Healthy control group show higher stride time variability compared to both geriatrics and patients with Parkinson's Disease, and acceleration vector magnitude symmetry is significantly higher in healthy control group compared to patients with Parkinson's Disease. A correlation network model, built using the mentioned discriminating gait parameters, show that healthy control subjects are clustered together while geriatrics and patients with Parkinson's' disease are grouped together in another cluster. Obtained results show that the proposed model is very promising and can be a starting point towards a robust population analysis technique for utilizing mobility data in assessing health levels and predicting potential health hazards.

Ray, Sam Poster Abstract

UNO human movement variability conference 2017

Augmenting Human Muscle Performance through Added Foot Stiffness

In human walking, the relationship between foot and ankle structure and function is not fully known. The foot and toe structures seem to dissipate energy while the ankle generates force through the plantarflexor muscles. Increasing foot stiffness through added carbon fiber insoles has been shown to increase force output and decrease contraction velocity of the ankle plantarflexors. This shift in the muscular force-velocity operating range may be beneficial in fast walking. During fast walking, muscle fascicles contract at high velocities and low force output. We predict that added foot stiffness can reduce the metabolic cost of fast walking by reducing muscle contraction velocity to a more favorable range. This research has potential applications in assisting impaired locomotion, whether from heavy load carriage, aging, or from musculoskeletal disorders.

Title: Influence of neuromuscular fatigue on the reliability of gait variability measures

Authors: Nicholas Reynolds & Vivien Marmelat

Abstract:

Walking in healthy young adults display an optimal pattern of variability from one stride to the next. This variability ensures that each step taken is not stereotyped but also not completely unpredictable, thus allowing the locomotor system to adapt and interact to an ever-changing environment. When compared to healthy young adults, healthy elderly present less optimal variability from stride to stride. Their stride to stride fluctuations become increasingly unpredictable and tend to go towards randomness. Previous studies have investigated differences in stride-to-stride characteristics comparing groups of young to groups of elderly. However, the consistency of gait variability measures on an individual level remains to be determined. Very little has been studied on whether or not an individual can display similar levels of variability consistently across different days or even within the same day of examination. The first aim of this study is to determine the between day and between trial consistency of gait variability measures in healthy young adults. This will be done by conducting multiple walking trials of 15 minutes repeated across consecutive days of examination. We hypothesize that there will be a high level of consistency from day-to-day and within day measure of gait variability. If confirmed, our results would suggest any changes in variability observed for a given individual would likely be the result of experimental constraints, not an artifact from the measurement.

With age, walking tends to become less stable, causing each step to become less correlated to previous steps. While a decrease of optimal gait variability is evident with aging, the origins of this are unclear. It is possible that impairments of the muscular systems increasing fatigue causes the inherent decrease in optimal gait variability. Similar to aging, fatigue can affect the ability of a muscle to contract maximally. Fatigue can be defined as any reduction in the force-generating capacity of a muscle due to recent activation and can be attributed to peripheral and central nervous system failure. Fatigue also has tendencies to decrease motor control performance, increase joint laxity, decrease balance skill, and decrease proprioception. How localized fatigue affects the gait of individuals is not well known due to fatigue being such a complex phenomenon. The second aim of this study is to determine how neuromuscular fatigue will affect stride-to-stride variability. This will be done through a squatting task to volitional fatigue. Following the fatigue task, we expect to see more randomness in stride to stride fluctuations, similar to what we see in older adults.

For this experiment, subjects will participate in a five-day collection. Reflective markers will be placed on the pelvis and on the feet to collect spatiotemporal measures. Marker data will be collected at 120 Hz using a 12-camera motion capture system. Briefly, subjects will walk at their preferred treadmill speed for three trials of 15 minutes each day from Day 1 to Day 3. On Day 4, they will begin with one trial of 15 minutes. This will be followed by the fatigue protocol and then two more 15 minute trials. Day 5 will be the same as Days 1-3.

RELATIONSHIP BETWEEN STEP-TO-STEP VARIABILITY AND METABOLIC COST OF TRANSPORT IN HUMAN WALKING

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INTRODUCTION

Humans typically walk in a way that makes efficient use of metabolic energy [1]. This is accomplished by a combination of walking speed and step length that minimizes the force and work requirements of the muscles. Therefore, if walking speed is constant, step length may be adapted to minimize energy use. Short steps (i.e. high cadence) are avoided because they require fast muscle contractions, which output little force [2]. Long steps (i.e. low cadence) are also inefficient, as they require extraneous vertical displacement of the center of mass [3]. This leads to an “optimal” step length that facilitates efficient locomotion. However, humans do not strictly adhere to a single step length or cadence; instead, fluctuations occur from step to step. When these fluctuations increase in magnitude, metabolic cost of transport also increases [4]. In addition to the magnitude of these fluctuations, their time-dependent organization may also be of interest.

Healthy gait patterns are characterized by “self-similarity”, where fluctuations over small time-scales (ten steps) resemble fluctuations over large time-scales (hundreds of steps) [5]. This self-similarity arises during normal human walking (similar to metabolic efficiency) and there is evidence it may be related to metabolic cost of transport. For example, deviations from the preferred walking speed negatively impact metabolic cost of transport [6] and also cause changes in gait variability: both magnitude of variability and self-similarity are affected [7]. However, the relationship between metabolic cost of transport and step-to-step variability has not been fully studied.

The purpose of this study is to investigate step-to-step variability in human walking and determine its relation to metabolic cost of transport.

METHODS

The participants walked on a treadmill at 5 speeds, ranging from 0.75 – 1.75 m·s⁻¹. Each condition lasted 15 minutes, and the order of conditions was randomized. Kinematic data were collected using a 12-camera system (Motion Analysis, Santa Rosa, CA; 100 Hz) in conjunction with anatomically placed retroreflective markers. Gait events were determined using foot velocities with respect to the pelvis [8].

For each condition, the magnitude and the self-similarity of step length fluctuations was calculated, using coefficient of variation (CV) and detrended fluctuation analysis (DFA), respectively. DFA estimates the scaling exponent DFA- α , a measure of self-similarity of the step length time series. Values close to 0.50 indicate random behavior, with increasing values denoting more self-similar behavior.

Metabolic cost of transport (MCOT) was calculated from inspiration/expiration rate of O₂/CO₂ obtained from a gas exchange monitoring system (Parvo Medics, Sandy, UT). Resting metabolic rate was subtracted from trial data, which were then used to calculate net metabolic power [9] and divided by speed to determine MCOT.

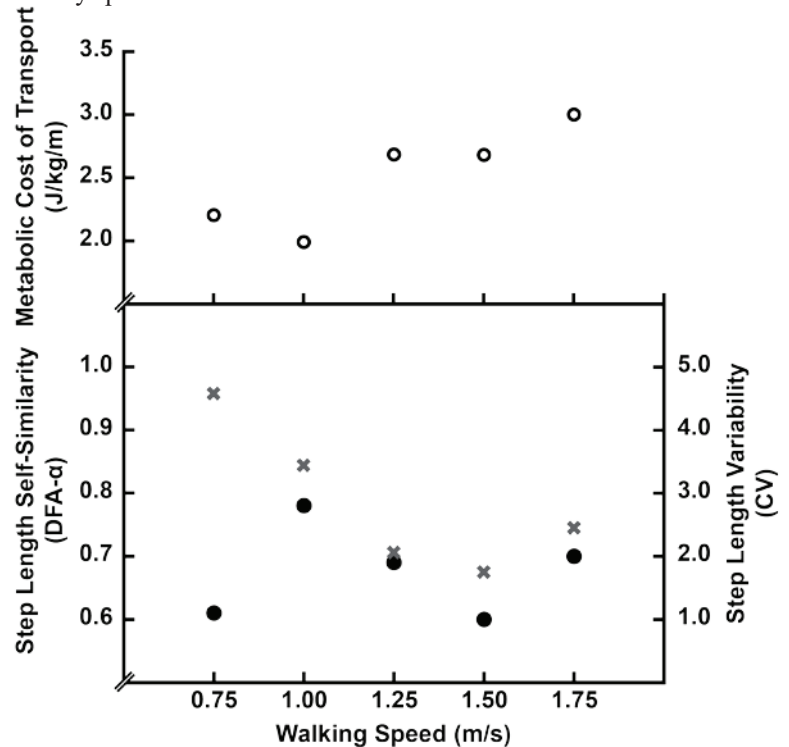


Figure 1. MCOT (○) at each speed, as well as the self-similarity (●), and CV (×) of step length of a single subject.

RESULTS AND DISCUSSION

MCOT was lowest and self-similarity was greatest at 1.00 m/s, providing support for a potential relationship. Because both variables are hypothesized to be “optimal” at the preferred walking speed, the identification of such a relationship would increase our understanding of neuromuscular control of gait. Results may also inform rehabilitation techniques where MCOT and self-similarity may be used in concert.

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ACKNOWLEDGEMENTS

This work is supported by a Graduate Research and Creative Activity Award from the University of Nebraska at Omaha; a NASA Nebraska Space Grant Fellowship; and the Center for Research in Human Movement Variability of University of Nebraska at Omaha, NIH (P20GM109090).

Samantha Sack

Abstract

Stroke is a major cause of adult disability in the United States and ambulation is a major goal of rehabilitation. During rehabilitation, many stroke-survivors adopt the use of over ground assistive devices to compensate for muscle weakness and aid with balance¹. While previous studies focus on the differences between walking with and without a cane, few studies have described the role of the cane itself in movement. For example, one study of stroke patients with hemiplegic gait showed that those walking with a cane exhibited spatial variable patterns and joint motion more similar to normal adults than those in the study who did not use a cane⁴. The cane adds stability for the user, thereby providing confidence to him or her and enabling him or her to take longer steps, faster. However, prior work has shown an evident decrease in paretic propulsion, a key aspect of gait, with the use of assistive devices³. So, although over ground assistive devices such as canes may add stability and encourage mobility, their use may be hindering overall rehabilitation and strengthening of the affected limb if users are relying on the cane too much or controlling it inappropriately. In other words, researchers have been inquiring whether cane use is beneficial and have not explored how to better use assistive devices to improve rehabilitation with the goal of transitioning to independent mobility. For many key rehabilitation variables, it is currently unknown how to best incorporate cane use to promote greater outcomes. In addition to previously studied variables such as paretic propulsion, it's been shown that movement or gait that is too variable or too mechanic may lower stability². Movement should exhibit fractal-like behavior, repeating similar gait patterns from step to step². The interaction and timing between the cane and gait should be studied, almost as though it is a third limb added to the gait phases, and altered to mimic this healthy, fractal behavior. To

determine to what extent variability is seen in a healthy adult using a cane, a single point, offset cane was instrumented with the technology to read exact impact forces and times. Timing data from the instrumented cane will be synced with wireless footswitch insoles (Noraxon) to determine the temporal relationship between foot and cane strike patterns. We will analyze the gait phases and timing of healthy individuals between the ages of 19-49 walking with and without a cane along level (indoor track) and outdoor surfaces (paved sidewalk). Timing will be compared between both cane and no-cane side. We hypothesize that for healthy individuals, the coordination between limbs and cane will follow the healthy 'fractal' pattern typical of free walking without use of a cane. We believe this knowledge can gauge the consequence of using canes and enable us to offer corrections. In the quest to progress rehabilitation, adoption of improved techniques is crucial and starts with understanding the benefits as well as the disadvantages of current methods.

- Theme of Research: clinical biomechanics

Comparison of axial tibial power flow pattern between patellofemoral pain syndrome and healthy females during the stance phase of running

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Introduction: Lower extremity joints act as a kinetic chain because of coordination existence among them; therefore, malfunction of one part of the chain could lead to malfunction of a more distal or proximal structure. It is reported that increased tibial internal rotation or excessive foot eversion could cause patellofemoral pain syndrome (PFPS).

In a recent study, it is reported that the strength of muscles of the lumbopelvic hip complex (core muscles) play essential role in controlling hip abduction, subsequent internal rotation of the femur, and potentially more distal movement. In addition, increased anterior rotation of the pelvis has been suggested to increase strain on the iliopsoas muscle causing internal rotation of the femur and subsequent dysfunction of the lesser gluteals. Therefore Dysfunction of hip abductors and external rotators has been suggested to lead to similar biomechanical changes as those attributed to excessive foot pronation.

On the other hand, there is evidence that supporting malfunction of distal structures in PFPS. Excessive or prolonged pronation is proposed to delay external rotation of the tibia and disrupt timing between knee extension and rearfoot supination. It is hypothesized if foot eversion causes tibial internal rotation during stance phase of gait, thus controlling foot eversion with foot orthoses could reduce tibial rotation leading to knee pain. However, if tibial rotation originates proximally to the tibia, and the foot merely follows the tibia, controlling eversion may increase the resistance against tibial rotation and cause more stress on the tibia and knee.

Research is needed to examine whether eversion causes tibial rotation or if tibial rotation is caused proximally for some patients during all or some parts of the support phase of the running and foot eversion is a result of this. Mechanical energy and power flow have been useful tools for evaluating and identifying the movement strategies. The purpose of this study was to assessment of the axial tibial power flow pattern in healthy and PFPS females during stance phase of running.

Materials and Methods: Six video cameras (JVC-9X00; 200 Hz) were arranged along an arc on the right side of a force plate, (Kistler, Winterthur, Switzerland; 1000 Hz) which was placed in the center of a 15 m runway. Three - dimensional kinematics and kinetics were recorded for 10 healthy and 22 PFPS females during running. Video and force-plate data were collected simultaneously to calculate the joint angles and axial tibial power flow. Mean axial tibial power during the first 40% of stance and the three phases of stance including loading response, mid stance, propulsion for

statistical analysis was determined. Between-group comparisons were assessed by independent sample T and Chi Square tests ($P \leq 0.05$).

Results: Results showed that, in healthy females during running 60% of subjects had mean negative power flow and 40% had positive power flow during first 40% of stance phase. However, in PFPS group was observed 68% negative power flow, but 32% positive power flow in barefoot running. During midstance, PFPS group demonstrated significantly higher mean axial power compared to healthy group ($p=0.04$).

Conclusion: The results of this study show that power flow could be unique from one person to another, and suggest the specific deficits to each person should be addressed.

Schleu, Mason

Assessing movement with mobile sensor data using linear and non-linear analyses

Balance disorders impact over 35% of Americans, causing substantial impact on quality of life due to psychological and physical hardships associated with poor balance. Balance disorder can affect anyone of any age, and range in seriousness from slight dizziness to the inability to safely walk from place to place. Most prominently susceptible are older adults, where injury from falling is a prevalent and grave concern. Studies show that once a certain age is reached, the chance of falling begins to increase exponentially every year. 20% of elderly falls lead to severe injury, and 27,000 fatalities occur every year as a result. Current state-of-the-art balance testing equipment such as the NeuroCom System have the potential to detect early signs of balance disorders, however these tests are prohibitively expensive, both from equipment cost and clinician time. This leads to individuals undergoing balance assessment only after the event of a fall or injury. A clinically relevant, low cost, self-service system in detecting such disorders does not exist. Previous research has shown the built-in accelerometer and gyroscope sensors of a smart phone to be valid tools in detecting standing balance performance using traditional linear analysis, however, such a system has yet to be proven useful in detecting dynamic postural variability. Indeed, more quantitative methods than are typically used in clinical settings are necessary for early detection of poor postural variability. Therefore, the purpose of this study is to determine if a low cost, self-service mobile sensor system is reliable in detecting balance performance during standing and walking tasks. This study will use non-linear analysis, through the calculation of sample entropy during static standing, and maximum Lyapunov exponent's during dynamic walking. A smart phone application will be developed to create a simple user interface and implement the objectives of this study. Participants in this study will perform the six stances of the Balance Error Scoring System (BESS) test for a standing balance examination, and then will proceed to a two-minute walking trial for dynamic data collection. We hypothesize that through the combination of a standing balance test and walking element of data collection, we will develop an accurate, reliable and low cost assessment for balance disorders. Previous research has proven these methods to be useful in isolation, but none have combined them in one assessment to look at the more complete description. The inclusion of a walking assessment will provide unique and important insight to the relationship between balance during standing and walking, as well as validate whether smart phone sensors can be a low-cost alternative to expensive lab grade equipment in detecting standing as well as dynamic balance issues. Through the collection of continuous mobile sensor data, dynamic postural variability can be assessed and will provide a low cost alternative to current standard balance testing.

Theme of Research: Interpersonal Coordination Dynamics

Title: Dynamics of Cooperation: Complexity Matching in a Collaborative Fitts' Task

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Fitts' task is a classic test of movement speed and accuracy in which a participant moves a pointer back and forth to alternately hit two targets on a surface. Task difficulty is manipulated in terms of distance between targets and target size, and an index of performance relates task difficulty with movement time. Some previous studies have extended the Fitts paradigm to dyadic conditions in which two individuals perform the task either side by side, or in coordination with each. Here we present an experiment that builds upon previous studies to investigate how performance in a collaborative Fitts' task relates to the coupling of dynamics across repeated, coordinated aiming movements. The task consisted of two pairs of vertically arranged target locations on either one touchscreen in an individual control condition, or two touchscreens in separate rooms in the dyadic condition. In the individual condition, a circular target 2.5 cm in diameter appeared in the upper left quadrant, and after the participant touched it with the left hand, the next target appeared in the upper right quadrant and the participant touched it with the right hand, and so on for the lower left and lower right quadrants. This cycle of four target locations was repeated 300 times (1200 total touches) per condition. In the dyadic condition, one participant used the left hand for the left-side targets, and the participant used the right hand for right-side targets (both touchscreens displayed all targets). To manipulate coupling between left and right sides, the targets drifted either randomly or dependently for each block of touches. Random drift consisted of successive shifts in target location in a random direction, with distance moved drawn from a uniform distribution between zero and the target radius. Dependent drift consisted of shifts to each subsequent location where the finger touched inside the circular target (drift was translated to each quadrant of the screen from touch to touch, and targets were kept within the boundaries of each quadrant). Performance was measured in terms of total time to complete a block of touches in each condition, and dynamics were measured as series of inter-touch time intervals (ITIs). Results showed that individuals performed slightly better than dyads, and random drift slowed movements relative to dependent drift. Spectral analyses showed that ITI variability was long-range correlated for each hand, and power law exponent estimates were greater for dyads versus individuals, and for dependent versus random drift. Coupling was measured in terms of complexity matching, i.e. correlations in exponent estimates between left and right hands. Complexity matching was reliable only for dyads in the dependent drift condition, suggesting that ITI variability was independent between the left and right hands of individuals. Finally, performance increased as complexity matching decreased for dyads, but not individuals. Further analyses indicated that this negative correlation occurred because dyads collaborated more effectively when they differentiated themselves—that is, when one person produced stable ITIs, and the other person exploited this stability to produce faster but less stable aiming movements.

Research Theme: Motor Control

Fitts' index of difficulty predicts the $1/f$ structure of movement amplitude time series

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Studies using a variety of experimental tasks have established that when humans repeatedly produce an action, fluctuations in action output are highest at the lowest frequencies and fluctuation magnitude (power) systematically declines as frequency increases. Such time series structure is termed *pink noise*. However, the appearance of pink noise seems to be limited to tasks where action is executed in the *absence* of task-related feedback. A few studies have demonstrated that when action was executed in the *presence* of task-related feedback, power was evenly distributed across all spectral frequencies—i.e., *white noise* was revealed. Here, participants produced cyclical aiming movements under visual feedback conditions and we sought to determine whether variations of both the movement amplitude requirement (A) and the target width (W)—in the form of the index of difficulty [$ID = \log_2(2A/W)$ —would predict the structure of movement amplitude (MA) time series. There were two ID levels, and there was a small- and large-scale version of each ID: The A and W values of the large-scale version were twice those used for the small-scale version. Given that increases in ID are known to induce increased reliance on the available visual feedback, we predicted an ID-induced shift in MA time series structure from pink to white noise. Indeed, that is what we found. Further, there were no changes in MA structure when scale level changed within each ID level. Such scale invariance of MA time series structure reinforces the notion that MA structure depends on the combined influence of A and W . A full report of the current presentation can be found in Slifkin & Eder (2014); other relevant research was reported in Slifkin & Eder (2012).

1. Slifkin, A. B., & Eder, J. R. (2012). Amplitude requirements, visual information, and the spatial structure of movement. *Experimental Brain Research*, 220, 297–310.
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Research Theme: Motor Control

Degree of target utilization influences the location of movement endpoint distributions

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According to dominant theories of motor control, speed and accuracy are optimized when, on the average, movement endpoints are located at the target center and when the variability of the movement endpoint distributions is matched to the width of the target (viz., Meyer, Abrams, Kornblum, Wright, & Smith, 1988). The current study tested those predictions. According to the speed-accuracy trade-off, expanding the range of variability to the amount permitted by the limits of the target boundaries allows for maximization of movement speed while centering the distribution on the target center prevents movement errors that would have occurred had the distribution been off center. Here, participants (N = 20) were required to generate 100 consecutive targeted hand movements under each of 15 unique conditions: There were three movement amplitude requirements (80, 160, 320 mm) and within each there were five target widths (5, 10, 20, 40, 80 mm). According to the results, it was only at the smaller target widths (5, 10 mm) that movement endpoint distributions were centered on the target center and the range of movement endpoint variability matched the range specified by the target boundaries. As target width increased (20, 40, 80 mm), participants increasingly undershot the target center and the range of movement endpoint variability increasingly underestimated the variability permitted by the target region. The degree of target center undershooting was strongly predicted by the difference between the size of the target and the amount of movement endpoint variability, i.e., the amount of unused space in the target. The results suggest that participants have precise knowledge of their variability relative to that permitted by the target, and they use that knowledge to systematically reduce the travel distance to targets. The reduction in travel distance across the larger target widths might have resulted in greater cost savings than those associated with increases in speed. A full report of the current research can be found in Slifkin & Eder (2017).

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3D Printed Prostheses: Not Just Plastic Toys

Theme of Research: 3D Printed Prostheses

Title: "3D Printed Prostheses: Not Just Plastic Toys"

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The purpose of this study was to determine whether or not upper-limb amputees could use and improve with 3D printed prostheses.

Subjects for this study were recruited through word of mouth and referrals from clinicians; 11 upper-limb amputees participated, all of whom were free of any known neurological defects. All subjects were children (ages 3-15) with no physical abnormalities, aside from amputation of an upper limb. Prostheses were designed in Autodesk Fusion 360, and were 3D printed on Ultimaker 2 Extended+ printers. To properly fit prostheses, a method of fitting described and validated by Zuniga et al. was used.

Upon receiving their prostheses, subjects completed the Box and Blocks test to establish baseline function with both their biological and prosthetic hands. No formal training was given, but subjects were asked to use and practice with their prosthesis. Roughly 6 months after prescription of the prosthesis, subjects returned and completed the Box and Blocks test again, to assess changes in proficiency.

To rule out effects of neural maturation due to children developing, subjects' biological hands were compared at baseline and 6 months. No difference was found in this comparison, and thus neural maturation played no role in change of function between baseline and 6 months. During this same period of time, however, function with the prosthetic limb greatly improved.

It is therefore suggested that – despite several claims to the contrary – 3D printed prostheses may be viable options for upper-limb amputees.

Between-day reliability of daily motor activity fluctuations in patients with Parkinson's disease
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Human daily motor activity (DMA) can be estimated from activity monitor recording bouts of activity (e.g., acceleration or steps number) at a certain frequency, e.g. every 15 seconds. Because the activity is not constant over time, the values change from one bout to the next, creating subtle DMA variability. DMA fluctuations have been evidenced to present complex temporal ordering and scale invariance. While typical measures of daily activity such as the total number of steps represent only the 'quantity' of activity, DMA fluctuations have the advantage to represent the 'quality' of activity, i.e. how the activity is distributed over time. Complex DMA fluctuations are hypothesized to reflect non-linear interactions between multiple physiological systems acting at different time scales, such as between the suprachiasmatic nucleus (SCN) and extra-SCN nodes. Aging and neurological disorders such as Parkinson's disease disrupt these interactions, which can be reflected in changes of DMA fluctuations. DMA fluctuations could be used a biomarker of circadian dysfunction, however it remains to be determined if DMA complexity levels are consistent between consecutive days for a given individual. The purpose of this study was to compare the reliability of the complex temporal fluctuations of DMA in healthy and pathological populations over a seven-day period. We made the hypothesis that DMA fluctuations would be reliable for all groups, but subjects with neurological disease would present lower level of complexity.

23 healthy young adults (HY group, 24.33 ± 3.52 years old), 28 healthy elderly (HE group, 65.15 ± 7.93 years old), and 14 PD patients (PD group, 70.31 ± 19.78 years old) wore an activity monitor Actigraph GT9X on their non-dominant hand for seven straight days. The data was sampled at 100 Hz and the Vector Magnitude (which represents the sum of acceleration in the three axis) was obtained every fifteen seconds. The Detrended Fluctuation Analysis (DFA) was used to estimate the scale invariance over an active 9 AM – 9 PM period. All zero numbers reflect periods where it was non-active and were taken out before the DFA was used. Briefly, the DFA computes the average size of fluctuations (F) for every window size n between 10 and $N/8$, where N is the length of the time series. The slope of $F(n)$ gives us the scaling exponent α -DFA. The reliability of the exponent α -DFA was tested using Intra-class correlations (ICC) Cronbach's alpha. We also compared the total number of steps for the first 14 participants in each group (to match the number of subjects in the PD group).

The ICC Cronbach alpha were equal to 0.7005 ($p < 0.001$), 0.8688 ($p < 0.001$) and 0.7345 ($p < 0.001$) for HY, HE and PD groups, respectively. The average α -DFA were equal to 0.92 (± 0.07), 0.92 (± 0.08) and 0.89 (± 0.05), for HY, HE and PD groups, respectively. There were no statistically significant differences between α -DFA values ($F(13,2)=0.4420$, $p=0.6475$). However, the total number of steps was significantly different between the three groups ($F(13,2)=37.07$, $p < 0.001$), the PD group presenting two times less activity compared to HY and HE groups.

Our results suggest that DMA complexity ('quality' of activity) is independent from the number of steps ('quantity' of activity). While suggesting that DMA fluctuations cannot discriminate between healthy and pathological populations, our results need to be confirmed with a larger PD cohort. This project also includes follow-up of another 7-day period after 6-months and 12-months, to determine if PD severity is associated with a change of DMA complexity toward more randomness.