Synergy activations are associated with post treatment gait in cerebral palsy

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INTRODUCTION

Cerebral palsy (CP) is a neuromuscular disorder caused by an injury to the brain which occurs at or near the time of birth. In CP, motor control is thought to be related to treatment outcomes. Muscle synergies, which identify weighted groups of muscles from experimental electromyography (EMG) data, have been used as a summary measure of altered motor control in CP. Walk-DMC, a summary measure of synergy complexity, has been shown to be associated with changes in kinematics and walking speed after treatment [1]. However, this measure does not evaluate how muscles are organized within synergies or how those synergies are activated. We sought to examine whether synergy weights or activations are related to treatment outcomes in CP.

METHODS

We retrospectively analyzed gait kinematics and EMG from clinical gait analysis of 147 children with CP and 31 typically-developing (TD) children. The children with CP were analyzed before and after treatment with botulinum toxin injections (n=52), selective dorsal rhizotomy (n=38), or single-event multilevel orthopaedic surgery (n=57). Muscles monitored with EMG recordings included the gluteus medius, medial hamstrings, lateral hamstrings, rectus femoris, vastus lateralis, gastrocnemius, soleus, and tibialis anterior. EMG data were preprocessed with a 20 to 500 Hz band-pass filter, then rectified, and a linear envelope was taken using a 10 Hz low-pass filter. Synergies were calculated from the processed EMG data using weighted non-negative matric factorization. Walk-DMC, a z-score of the total variance accounted for by one synergy relative to the TD group, was calculated for each child. Additionally, the four-synergy solution was computed for each child and the synergy weights and activations were compared to the average unimpaired synergies of the TD group using cosine similarity. Higher similarity indicates weights and activations that are closer to the TD group.

We evaluated changes in gait after treatment with two measures: the Gait Deviation Index (GDI) [2] and dimensionless walking speed. We used forward stepwise linear regression models to find a set of regressor variables that were significantly associated with post-treatment gait. Possible regressors were pre-treatment GDI, walking speed, age, treatment group, and the three measures of synergies (walk-DMC, and average cosine similarity of synergy weights and activations relative to TD). The identified models were re-computed using the remaining two measures of synergies to determine what effect they have on the models.

RESULTS AND DISCUSSION

Forward stepwise regression identified pre-treatment GDI, treatment group and pre-treatment synergy activations as significant regressors of post-treatment GDI (Figure 1). Similarly, we identified pre-treatment walking speed, and pre-treatment walk-DMC as significant regressors of post-treatment walking speed. When synergy activations were used in the model in place of walk-DMC we found synergy activations were also significantly associated with post-treatment walking speed, with an effect size slightly smaller than that of walk-DMC. Synergy weights were not significantly associated with either post-treatment outcome measure.

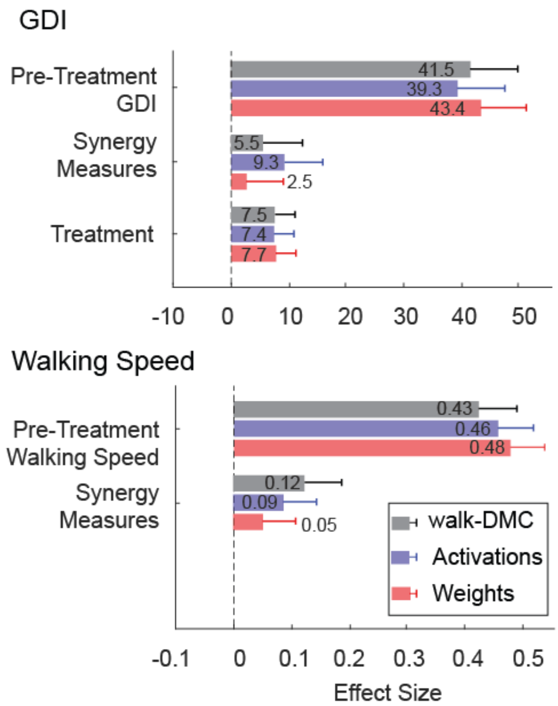

Figure 1: Effect size of linear regression models with pre-treatment measures of synergies (walk-DMC, activations, and weights) as explanatory variables of post-treatment GDI (top) and dimensionless walking speed (bottom).

CONCLUSIONS

Synergy activations that more closely resembled TD activation patters before treatment were associated with better post-treatment gait (GDI and walking speed). These associations were similar or larger than walk-DMC, suggesting that examining the timing of synergies may provide additional useful information about an individual's motor control to aid treatment planning.

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DO MALES AND FEMALES DISPLAY DIFFERENT CUTTING, DROP-JUMPING, AND RUNNING BIOMECHANICS POST-ACL RECONSTRUCTION?

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INTRODUCTION

Anterior cruciate ligament (ACL) tears are a common orthopedic sports injury. Female athletes have an incidence rate 1.7 times greater than males throughout a sports season [1]. Once injured, ACL surgical reconstruction (ACLR) is the most common intervention, with a 6-12 month recovery before return to sport. ACLR is believed to be the best method for reestablishing knee stability. However, despite successfully returning to sport or activity, recent evidence suggests that lower-extremity (LE) biomechanics during running, cutting, and jumping may still be different post-ACLR compared to healthy athletes [2,3]. It is currently unclear whether these biomechanical differences are sex-dependent. Therefore, the purpose of this study was to compare running, cutting, and jumping LE biomechanics between males and females post-ACLR.

METHODS

Subjects consisted of eight males (age = 30.4 ± 4.8 yrs) and nine females (age = 29.5 ± 7.5 yrs) who had torn their ACL, were at least 1-year post-ACLR, and cleared by their orthopedic surgeon to return to full sports activity. Prior to participating in this study, all subjects signed an informed consent form approved by Oregon State University.

During testing, all subjects wore a standard New Balance (Boston MA) running shoe and were outfitted with twenty-one reflective markers and six marker clusters. Three-dimensional kinematics were collected with an eight camera Vicon motion analysis system (Vicon Motion Systems, Oxford UK) sampling at 250 Hz during three tasks: running, cutting at a 45° angle, and drop vertical jumping (DVJ). Two in-ground force plates (AMTI, Watertown MA) sampling at 1000 Hz were used to identify foot-strike and toe-off. Five successful trials of each task were recorded.

Visual3D™ software (C-Motion, Germantown MD) was used to calculate hip, knee and ankle joint kinematics. The variables of interest included peak angles for ankle eversion, knee valgus, knee flexion, hip internal rotation, hip flexion, and hip adduction. Differences between sexes were calculated using independent sample *t*-tests with the alpha-level set to 0.05.

RESULTS AND DISCUSSION

During cutting, females displayed greater peak knee valgus (females: 9.8 ± 4.5°; males: 5.1 ± 3.0°, $p = .025$) and peak hip adduction (females: 2.1 ± 7.3°; males: -4.4 ± 4.1°, $p = .043$) (Figure 1).

During running, females displayed greater peak hip adduction (females: 14.6 ± 4.1°; males: 8.8 ± 4.9°, $p = .024$) and a trend towards greater peak knee valgus (females: 5.4 ± 4.3°; males: 1.9 ± 3.8°, $p = .094$) (Figure 2).

There were no sex-specific differences in LE biomechanics during the DVJ and no other differences identified for during the cutting and running task.

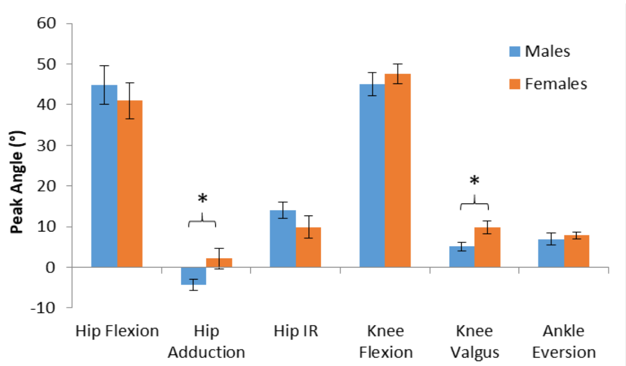

Figure 1: ACLR females displayed significantly greater peak hip adduction and peak knee valgus compared to ACLR males during cutting.

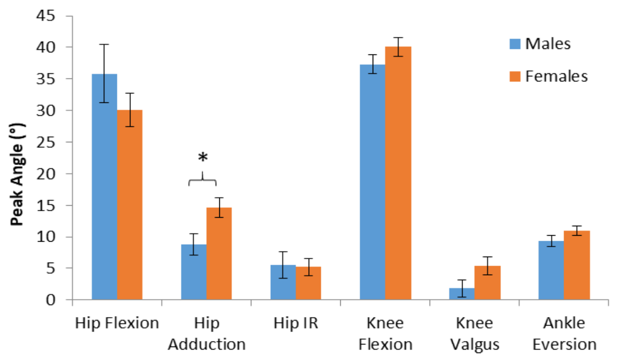

Figure 2: ACLR females displayed significantly greater peak hip adduction and a trend towards peak knee valgus compared to ACLR males during running.

CONCLUSIONS

Compared to ACLR males, females who have had their ACL reconstructed exhibited cutting and running biomechanics that may place them at a greater risk for ACL re-injury. These findings suggest that post-ACLR rehabilitation programs may not be as effective at improving LE biomechanics in the female ACLR population compared to males. One limitation of this study was that subjects' pre-ACLR biomechanics are unknown. Future studies should systematically measure LE biomechanics across sexes post-ACLR and determine if sex-specific rehabilitation protocols are necessary.

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WEARABLE TECHNOLOGY TO MONITOR HAND MOVEMENT DURING CONSTRAINT-INDUCED MOVEMENT THERAPY FOR CHILDREN WITH CEREBRAL PALSY

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INTRODUCTION

Cerebral palsy (CP) is a non-progressive neurologic disorder of movement and posture that affects approximately 2 in every 1000 children in the United States [1]. Of these children, 40% have unilateral or hemiplegic CP, with abnormal tone, decreased strength, dystonia, and other muscle impairments impacting movement on one side of the body [2]. Constraint-Induced Movement Therapy (CIMT) is an evidence-based treatment for children with CP that places the child's non-impaired hand in a cast to encourage greater use of the impaired hand [3]. While CIMT has been shown to improve hand function, the results are often variable [4].

We sought to evaluate hand use during CIMT using wrist-worn accelerometers. We hypothesized that (1) impaired hand use would increase during CIMT, and (2) that increased hand use during CIMT would be associated with enhanced bimanual use in daily life after CIMT.

METHODS

We recruited eight children with hemiplegic CP undergoing CIMT (age: 3yr 5m – 9yr 2m, 4 boys/4 girls) and five typically-developing (TD) children (age: 2yr 8m – 9yr 10m, 1 boy/4 girls) from a pediatric tertiary care facility.

Per the institution's CIMT protocol, the non-impaired hand of each child in the CP cohort was placed in a cast for three weeks. Unilateral hand training of the impaired hand occurred in the clinic for 2 hours/day, 4 days/week and bimanual training 2 hours/day once a week. The CP cohort wore ActiGraph GT9X Link (ActiGraph Corp., Pensacola, FL) tri-axial accelerometers on both wrists for 3 consecutive days during three time periods: 1-week before, during, and 6-8 weeks after CIMT. Functional tests (grip strength and Box & Blocks) and the Canadian Occupational Performance Measure (COPM) were completed before and after CIMT. The TD cohort did not receive therapy, but wore the Actigraph accelerometers on both wrists for three consecutive days at home, on three occurrences temporally aligned with the CP cohort time periods.

Accelerometry data were analyzed using the magnitude ratio (MR) and bilateral magnitude (BM) [5]. The MR is the natural log of the vector magnitude of the impaired limb divided by the non-impaired limb. Values outside of the range ±7 were set to ±7 to constrain the range of values, similar to prior research [5]. The BM is the sum of the vector magnitude of the impaired and non-impaired hands.

RESULTS AND DISCUSSION

Although CIMT encouraged children with CP to use their impaired hand more compared to their non-impaired hand during therapy (Table 1), they returned to baseline values 6-8 weeks post CIMT. Although the BM decreased for children during CIMT, the increase after CIMT demonstrated that children were using their hands together more and at the same magnitude as the TD cohort. During CIMT, this may be reflective of the non-impaired hand being casted and therefore not being able to move. After CIMT, the CP cohort scored higher on impaired hand functional measures: grip strength increased by 7.5±4.9 lbs. and the number of blocks transferred in 60 seconds increased by 3.5±6.6 blocks. Furthermore, COPM scores increased 5±2.8 points, indicating that children in the CP cohort felt more confident achieving specific self-identified goals.

CONCLUSIONS

The increase in MR levels and functional measure scores suggests that children feel more confident using their impaired hand following CIMT. However, the subsequent return to pre-intervention BM values, as measured by accelerometry data, indicates that further interventions (i.e., a larger dose of CIMT and/or weekly follow-up therapy sessions) and strategies may be needed to maintain increased daily impaired hand use after CIMT.

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Table 1: Comparison of Magnitude Ratio and Bilateral Magnitude for TD and CP Participants

	Magnitude Ratio		Bilateral Magnitude	
	Mean	**Range**	**Mean**	**Range**
Typically Developing	-0.2 ± 0.2	-0.7 – 0.3	92.9 ± 22.3	43.2 – 119.6
CP – Before CIMT	-1.9 ± 0.4	-2.3 – -1.2	73.4 ± 21.4	45.4 – 109.8
CP – During CIMT	1.9 ± 0.4	1.1 – 2.5	48.2 ± 15.6	23.5 – 70.9
CP – After CIMT	-2.0 ± 0.3	-2.2 – -1.6	95.0 ± 28.3	74.6 – 127.3

Sex and Limb Impact Lower Limb Biomechanics During Loaded Single Leg Cuts.

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INTRODUCTION

Female soldiers are two times more likely to suffer a musculoskeletal injury than males during military activities [1]. During military activities, soldiers don body borne loads that range between 20 kg and 40 kg while performing dynamic tasks, such as a single-leg cut [2]. These loads result in lower limb biomechanics that elevate risk of musculoskeletal injury. Body borne load increases peak hip and knee moments and reduces peak hip and knee flexion angle during a single-leg cut [3]. Females exhibit a sex dimorphism in lower limb biomechanics during unloaded single-leg cuts that may elevate their risk of musculoskeletal injury. However, it is unknown if a similar sex dimorphism exists during loaded single-leg cuts.

METHODS

11 female and 17 male participants (1.74 ± 0.09 m, 75.69 ± 11.55 kg, 21.76 ± 2.66 years) had 3D lower limb biomechanics quantified during a series of single-leg cuts. Participants performed the cuts with four load conditions: 20, 25, 30 and 35 kg. For each load, participants carried a mock weapon, and wore a military issue helmet and weighted vest that was systematically adjusted to add the required load for each condition. The single leg cut require participants run at 3.5 m/s ± 5%, before planting either their dominant or non-dominant foot on a force platform and cutting 45° towards the opposite limb. Participants completed five successful cuts off each limb.

During each single leg cut, lower limb biomechanics were quantified from 3D trajectories of 34 retroreflective markers. Synchronous GRF data and marker trajectories were low pass filtered with a fourth-order Butterworth filter (12 Hz). Filtered marker trajectories were processed to solve for 3D joint rotations, while filtered kinematic and GRF data were processed using conventional inverse dynamics to calculate joint moments and knee joint forces. Proximal anterior tibial shear force was calculated as the anteriorly directed y-axis force occurring at the proximal tibia.

For analysis, peak stance (PS: 0%-100%) hip and knee flexion, hip adduction and internal rotation, and knee abduction and external rotation angles and moments, and peak proximal tibial shear were calculated. Each variable was submitted to a RM ANOVA to test the main effect and interaction between load (*20 kg, 25 kg, 30 kg, 35 kg*), sex (*male, female*), and limb (*dominant, non-dominant*). Significant interactions were submitted to simple main effect analysis and a modified Bonferroni procedure was used for multiple comparisons.

RESULTS AND DISCUSSION

Body borne load may increase risk of knee injury during a single-leg cut, particularly for females. Peak proximal tibial shear force was significantly larger with the 35 kg compared to 20 kg ($p=0.011$) (Table 1), increasing knee forces thought to produce ACL loads and increase injury risk. But, females exhibited a significant increase in peak proximal tibial shear force with the 25 kg compared to 20 kg ($p=0.028$), whereas, males did not exhibit a significant increase in proximal tibial shear until donning the 35 kg load configuration compared to the 20 ($p = 0.04$) and 25 ($p = 0.011$) configurations.

Females exhibited hip and knee biomechanics reported to increase dynamic valgus loads at the knee, which may further elevate their injury risk during the single-leg cut. Females exhibited greater PS hip adduction angle ($p=0.015$) and moment ($p<0.001$), and knee external rotation ($p=0.004$) moment compared to males. Males, however, relied on greater sagittal plane moments to complete the cut. Males exhibited greater PS hip ($p=0.041$) and knee flexion moments (25 kg: $p = 0.04$; 30 kg: $p = 0.022$) compared to females. These sagittal plane loads may afford males the ability to successfully execute the cut, but also increase strain on the knee's soft tisue structures.

Both limbs exhibited biomechanics associated with dynamic knee valgus loads, but only the non-dominant limb may elevate risk of injury with the addition of load. The dominant limb exhibited greater PS hip adduction moment ($p=0.010$), whereas, the non-dominant limb exhibited greater PS hip internal rotation angle ($p=0.05$) and moment ($p=0.07$), and knee abduction ($p=0.047$) and external rotation ($p=0.003$) moments. But, only the non-dominant limb exhibited a significant increase in PS knee abduction moment ($p=0.003$), and potential valgus knee loads, with addition of load.

CONCLUSIONS

Body borne load may elevate risk of knee injury for military personnel. During the single-leg cut, the addition of load placed larger loads on the joint's soft-tissues, particularly for females. Both females and the non-dominant limb exhibited lower limb biomechanics thought to produce knee valgus loads that may elevate their injury risk when performing loaded single-leg cuts.

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Table 1: Proximal anterior tibial shear force and knee abduciton moment for both sexes and limbs.

		20 kg		25 kg		30 kg		35 kg	
		M	**F**	**M**	**F**	**M**	**F**	**M**	**F**
Proximal Tibial Shear (Wt)	**Dom**	0.105	0.120	0.106	0.130	0.110	0.133	0.131	0.135
	Non	0.103	0.110	0.101	0.151	0.100	0.133	0.121	0.134
KAM (Nm/Kg*m)	**Dom**	0.360	0.266	0.304	0.225	0.383	0.241	0.413	0.249
	Non	0.338	0.221	0.449	0.257	0.386	0.276	0.426	0.365

PATELLOFEMORAL JOINT STRESS IN FEMALE WEIGHTLIFTERS AT DIFFERENT SQUAT DEPTHS AND LOADS

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INTRODUCTION

The squat is a key exercise in sports conditioning. However, there are mixed philosophies regarding proper loads and depths for squatting, since changing load or depth might increase knee joint loading. One specific concern is how patellofemoral joint stress (PFJS) changes with these factors, as PFJS is related to the development of patellofemoral pain syndrome and is associated with osteoarthritis. While some studies have assessed the influence of squat depth on PFJS [1] and others have assessed load [2], to date, no studies have assessed PFJS in females squatting at different depths, and with different percentages of one repetition maximum (1RM). Therefore, the purpose of this study was to analyze PFJS in females back-squatting at three different loads and three different depths.

METHODS

13 experienced female weightlifters (age: 24.7 ± 6.0 years; mass: 64.3 ± 7.7 kg; experience: 4.5 ± 2.8 years) participated in this study. A 1RM was determined for each back-squat height: above parallel (knee flexion: 96.9 ± 1.9°), thighs parallel to ground (knee flexion: 113.9 ± 3.2°) and full depth (knee flexion: 138.4 ± 0.2°). A field laser, providing both visual and auditory cues, was used to ensure squat depth consistency. In a second session, participants squatted at 0%, 50%, and 85% of 1RM in a randomized order of depth and load. Kinematic data was collected at 250 Hz using a 12-camera motion capture system (Qualysis). Ground reaction forces were acquired at 1000 Hz using a Bertec force plate under each foot. Kinematic data were filtered at 8 Hz with a 4th order Butterworth filter. Kinetic data were filtered at 15 Hz with a 4th order Butterworth filter.

Peak PFJS during each squat was calculated using a previously described biomechanical model of the patellofemoral joint, where PFJS is the patellofemoral joint reaction force divided by the patella contact area [2,3]. Effective quadricep lever arm for the patellofemoral joint reaction force was calculated as a function of knee flexion angle from van Eijden et al. [3]. Patella contact area was calculated as function of knee flexion angle according to a polynomial fit of contact area values found by Matsuda et al. [3].

A 3x3 (depth x load) repeated measures ANOVA was used to assess differences in peak PFJS between conditions. Where a significant main effect was observed post-hoc comparisons were conducted using a Bonferroni correction. Alpha of p <0 .05 was used for all comparisons.

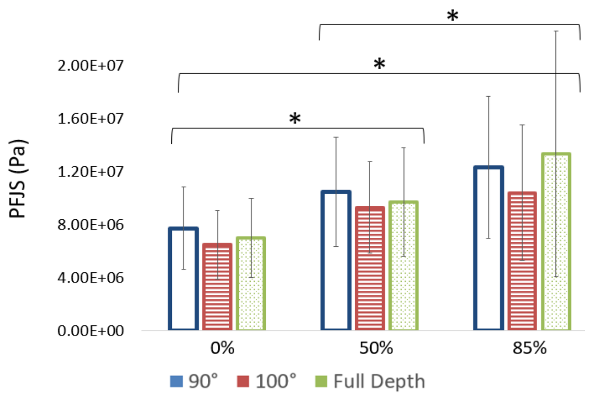

Figure 1: PFJS for different squat depths, as grouped by the load as percent of 1RM. * indicates a difference for p < 0.05.

RESULTS AND DISCUSSION

There was no depth by load interaction ($F_{4,48}$ = 0.651, p = 0.629) and no main effect of depth ($F_{2,24}$ = 1.984, p = 0.159). There was a significant main effect of load ($F_{2,24}$ = 18.645, p < 0.001). Post-hoc comparisons showed that as load increased, peak PFJS increased. Peak PFJS at 85% 1RM (12.03 ± 6.76 MPa) was greater than either 50% 1RM (9.81 ± 4.05 MPa, p =0.047) or unloaded (7.09 ± 2.96 MPa, p =0.002). PFJS at 50% 1RM was also greater than unloaded (p <0.001, Figure 1).

Our results agree with previous work which has shown that PFJS changes with increasing load [2], but not with increasing depth of squat [1]. Based on these results, if reducing PFJS during squatting is the primary concern then this is best done by removing load, rather than by modifying the depth of the squat, as is commonly recommended. However, other factors such as center of mass position, anthropometrics, and hip rotation may provide additional of future research for decreasing PFJS

CONCLUSIONS

For experienced female weightlifters tested at various squat depths and percentages of 1RM, our results demonstrated that load influences PFJS whereas squat depth does not.

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A HAPTIC BIOFEEDBACK CANE TO REDUCE DEGENERATIVE LOADING IN THE ARTHRITIC KNEE

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INTRODUCTION

Osteoarthritis (OA) is the most common joint disorder and the leading cause of disability in adults [1]. It is thought that at least 37% of adults over the age of 65 exhibit evidence of knee OA [2]. Medial compartment knee loading is thought to play a key role in the development and progression of knee OA [3]. The knee adduction moment (KAM), a proxy for medial compartment loading, is associated with the rate of OA progression [4]. When properly used, walking canes can reduce the KAM [5], however most cane users under-load their cane and thus do not receive the maximum beneficial knee unloading [6].

To provide patients with a practical, intuitive solution to improve cane loading, we developed a walking cane with haptic biofeedback which alerts the user when the target amount of force has been applied to the cane. The purpose of this study is to compare the efficacy of the haptic cane to that of a traditional walking cane in terms of cane loading and KAM reduction. Proper and constant cane loading over time may slow the progression of OA, reduce pain, delay surgery, and improve mobility.

METHODS

Nineteen individuals who had experience using a walking cane and reported clinically diagnosed knee OA were recruited for the study. Subjects were given the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) questionnaire, commonly used to assess the impact knee OA has on day-to-day life [7]. All subjects gave their informed consent to participating in the IRB approved study.

Participants attended a single lab session for collection of kinematic, kinetic, and biometric data. During the data collections, participants were instructed to walk at SSW along an approximately 20-meter path containing five force plates. Twelve Vicon motion capture recorded marker positions. Walking trials were carried out under five conditions: C1) a conventional cane with no instruction (naïve), C2A) a conventional cane with scale training, C2B) a conventional cane with no further instruction, C3A) the haptic biofeedback cane with an explanation of the feedback mechanisms, and C3B) the haptic biofeedback cane with no further instruction.
The order of conditions C2 and C3 were randomized at the beginning of data collection to avoid a learning bias. During "scale training" participants practiced applying the suggested 20% BW to their canes using a beam scale that had been set to the correct weight, until they felt comfortable recreating the technique (usually less than five minutes). Before the 'B' conditions, a five-minute break was taken to test short-term instruction retention. For each condition, between 5 and 8 successful walking trials were collected. The KAM was calculated in Visual3D using standard inverse dynamics techniques and exported to MATLAB to determine the peak KAM (PKAM) and knee adduction angular impulse (KAAI), as well as their associated averages and SD's. Multivariate models for PKAM and KAAI were created to determine statistical significance of the outcomes measures.

RESULTS AND DISCUSSION

Compared to naïve cane loading, both scale training and use of the haptic biofeedback cane significantly increased cane loading. Scale training had greater cane load variability than the haptic cane. Scale training and use of the haptic biofeedback cane reduced KAM across stance phase with the primary reductions occurring in late-stance (Figure 1). The PKAM was statistically significantly reduced (p = 1e-04) from 2.56 ± 0.94 %BW*Ht in the naïve condition to 1.75 ± 0.84 %BW*Ht in trials using the haptic cane (C3A). The KAAI had a similar statistically significant reduction (p = 0), from 1.38 ± 0.19 %BW*Ht*s (naïve) to 0.553 ± 0.23 %BW*Ht*s for the haptic cane condition (C3A). Improving the design, usability and efficacy of common walking aids through biofeedback serves those with OA improving conservative treatment options.

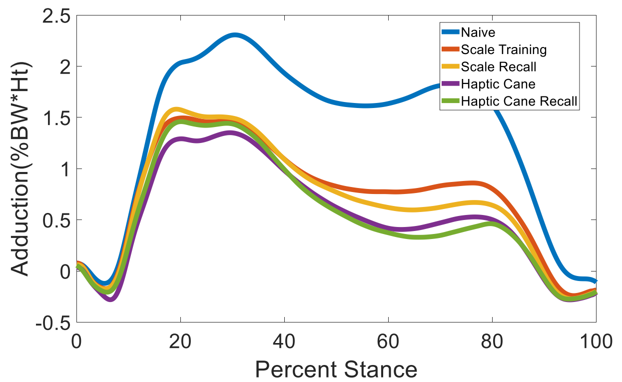

Figure 1. Mean KAM of 19 subjects' arthritic knee during stance phase across the tested conditions

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