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The effects of age and step length on joint kinematics and kinetics of large out-and-back steps

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Abstract

Background—Maximum Step Length is a clinical test that has been shown to correlate with age, various measures of fall risk, and knee and hip joint extension speed, strength, and power capacities, but little is known about the kinematics and kinetics of the large out-and-back step utilized.

Methods—Body motions and ground reaction forces were recorded for 11 unimpaired younger and 10 older women while attaining Maximum Step Length. Joint kinematics and kinetics were calculated using inverse dynamics. The effects of age group and step length on the biomechanics of these large out-and-back steps were determined.

Findings—Maximum Step Length was 40% greater in the younger than in the older women ($p < 0.0001$). Peak knee and hip, but not ankle, angle, velocity, moment, and power were generally greater for younger women and longer steps. After controlling for age group, step length generally explained significant additional variance in hip and torso kinematics and kinetics (incremental $R^2 = 0.09$ – 0.37). The young reached their peak knee extension moment immediately after landing of the step out, while the old reached their peak knee extension moment just before the return step lift off ($p = 0.03$).

Interpretation—Maximum Step Length is strongly associated with hip kinematics and kinetics. Delays in peak knee extension moment that appear to be unrelated to step length, may indicate a reduced ability of older women to rapidly apply force to the ground with the stepping leg and thus arrest the momentum of a fall.

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Conflict of interest statement

None of the authors have any financial or personal relationships with any people or organizations that could benefit from or bias this work in any way.

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Keywords

biomechanics; stepping; step length; strength; speed; power; falls; aging

1. Introduction

Falls are a leading cause of accidental death and injury for those over the age of 65 years (CDC, 2000) and older women, especially those with balance impairments, are at a particularly high risk for fall-related injuries (Baker et al., 1992). The ability to recover from an imminent fall has been shown to be dependent on the ability to take a rapid and adequately long step in the direction of the fall (Alexander, 1994; Luchies et al., 1994; Maki and McIlroy, 1999; Thelen et al., 1997).

Most tests of volitional stepping evaluate only step timing and do not take into account step length (Cronin et al., 2003; Lord and Fitzpatrick, 2001; Luchies et al., 2002). While rapid stepping is important, longer steps may be required to recover balance and greater step distances are likely to place greater physiological demands on the leg musculature. Given that strength (Frontera et al., 1991; Lexell, 1995), peak contraction velocity (Hortobagyi et al., 1995; Larsson et al., 1979), and particularly power (Hakkinen et al., 1997; Izquierdo et al., 1999; Macaluso and De Vito, 2003) decline with age, might these declines be related to step length?

In one measure of stepping ability, volitional stepping, Medell and colleagues (Medell and Alexander, 2000) instructed subjects to step out as far as possible and return to the original stance position in one step. This Maximum Step Length (MSL) was found to decline with age and balance impairment and correlate strongly with measures of balance, fall risk, mobility performance, and self-reported disability in balance-impaired older adults (Cho et al., 2004; Lindemann et al., 2003; Medell and Alexander, 2000). MSL was recently shown to also improve with training (Nnodim et al., 2006). MSL test-retest reliability was satisfactory and, while MSL was originally conducted in three directions (forward, sideways, and backwards) with both right and left feet, a simplified version more appropriate for clinical settings (right foot forward only) and equally predictive of the above functional outcomes (Cho et al., 2004) was evaluated in the present study.

MSL thus appears to be a measure of fall risk as well as other mobility-related factors. Yet, as in many clinical mobility tests, little is known about the mechanisms underlying decreased MSL values associated with increased age and fall risk. While recent findings have indicated that MSL correlates with knee and hip extension strength, speed, and power generation even after controlling for age group (Schulz et al., 2007), the actual joint kinematics and kinetics used to perform the MSL are not yet known.

Biomechanical analyses of relevant clinical tests such as the MSL help provide a better understanding of the key contributors to clinical test performance (such as in leg power), and ultimately, better insight into how changes in these parameters might lead to declines or improvements in mobility performance. Thus, the goal of this study was to determine the relationships of age and step length with the MSL kinematics and kinetics. To accomplish this we recorded body segment kinematics during the original out-and-back MSL version and calculated the stepping leg joint kinetics using an inverse dynamics model. We restricted our analysis to the MSL phase with the greatest joint moments and power. Thus, we hypothesized that maximal values for joint kinetics would occur during the “pushback” phase of the MSL. Furthermore, based on prior data (Schulz et al., 2007) showing little independent effect of age on the correlations between MSL and dynamometer-measured knee and hip extension strength, speed, and power, we similarly hypothesized that any correlations of step length with inverse-

dynamics-calculated peak knee and hip extension velocity, moment, and power generated would be independent of age.

2. Methods

2.1. Subjects

Eleven younger (mean [SD] age 24[3.4] years) and ten older (mean age 73[5.3] years) unimpaired women participated in this study. All younger subjects completed a medical questionnaire and all older subjects were physically screened by a geriatric nurse-clinician supervised by the physician-geriatrician prior to testing. The older women had no significant abnormal neurological or musculoskeletal findings on directed history and physical. The two groups were of similar stature, but the younger women weighed less than the older women ($p=0.008$ for weight and $p=0.003$ for Body Mass Index, Table 1). All subjects wore their own athletic shoes for Maximum Step Length (MSL) testing.

2.2. Instrumentation

Each foot was initially located on a ground-level force plate (model OR6-7-1000, Advanced Mechanical Technologies, Inc., Watertown, MA, USA) and two additional force plates were located at the possible step landing positions (Fig. 1). Optoelectronic markers (Optotrak 3020, Northern Digital, Inc., Waterloo, Canada) were placed and joint centers determined as per the methods of (Thelen et al., 1997). Infrared emitting diodes were located on the right leg over the lateral metatarsal, heel, lateral malleolus, lateral fibula head, and lateral epicondyle; and on the thigh, midway between the knee and greater trochanter. Four diodes were placed on the medial side of the left leg: at the medial metatarsal, heel, medial malleolus, and medial tibial head. A diode placed on the right shoulder tracked torso motion and a three-marker wand attached to the right hip identified the right hip joint center.

2.3. Testing protocol

After a standardized warm-up consisting of stretching, walking in place, and short practice steps, the subject performed five blocks of five steps with several minutes of rest between each block. Three different versions of each subject's MSL were tested during this session (Schulz et al., 2007), but only the data from the last block of the original "out and back" MSL (block four of five) were examined here to minimize any practice or training effects.

To perform the original "out and back" MSL (Medell and Alexander, 2000) each subject was instructed to step out as far as possible and return to the starting position using a single step (Fig.1). Only the right leg was tested and trials were considered failures if more than a single step was used, the arms were uncrossed, or the return step landed anterior to the initial lift off position. Feedback and encouragement were given between each trial by a spotter (same one for all subjects) located next to the foot landing position. Actual step lengths and foot placement errors were determined from foot marker positions.

The steps of the MSL were divided into four distinct phases by ground contact of the stepping leg. 1) "Pushoff" was the dual-contact phase prior to initiation of the step out. 2) "Swingout" was the aerial phase during which the stepping leg swings to the stepped-out position. 3) "Pushback" was the dual-contact phase with the feet in the stepped-out position. 4) "Swingback" was the aerial phase as the stepping leg returns to the starting position. All subsequent analyses were limited to the phase with the greatest kinetic demands on the stepping limb.

2.4. Data processing and analysis

Custom software routines in Matlab v6.5 (The MathWorks, Natick, MA, USA) were used to process all data. Force plate data were sampled at 1 kHz and marker data were sampled at 100 Hz. Second-order Butterworth filters, with forward and backwards passes, were used to minimize phase shift. The force plate data were filtered at 30 Hz and the marker data were filtered at 6 Hz. Joint moments were re-filtered at 30 Hz to eliminate additional noise spikes caused by the numerical differentiation. This did not introduce observable amounts of phase shift or peak attenuation to the data. Step liftoffs and landings were indicated by a 25% body weight force plate threshold to eliminate problems caused by the stepping foot intermittently contacting the ground on the return step. Steps counted as errors were excluded from all analysis. If any part of any stepping foot landed off the farthest force plate, that step was excluded from kinetic analysis. This only occurred three times for one young subject.

Segment masses and center-of-mass (COM) locations were calculated from the individual subject anthropometry using established values (de Leva, 1996). The arm masses and COM locations were neglected in the determination of the head-arms-torso COM, as the proximity of the crossed arms to the head-torso COM and much smaller relative mass of the arms would have little effect on the head-arms-torso COM location.

Joint angles, velocities, moments, and powers were calculated using a custom three-dimensional inverse dynamics algorithm using similar methods as Vaughan et al. (Vaughan et al., 1992). Step length and joint moments and powers were normalized to subject height and weight as appropriate. All data were temporally normalized such that the phase began at 0% and finished at 100%. All data were then averaged across all acceptable steps for each subject, yielding “ensemble means” of the normalized velocity, moment, and power profiles.

Dynamometer measurements of knee and hip extension strength, speed, and power capacity were taken from each subject as described and reported elsewhere (Schulz et al., 2007).

2.5. Statistical analysis

Hypotheses were posed based upon previous findings relating knee and hip extension capacities to MSL (Schulz et al., 2007), but because the inverse dynamics model used here permitted the determination of flexion and extension variables at the ankle, knee, and hip, all data were tested and statistical tests appropriately corrected.

Independent t-tests were used to compare subject group differences in height, weight, body mass index. One-way analyses of variance using single-degree-of-freedom planned post-hoc contrasts were used to test if the pushback phase required greater stepping leg ankle, knee, and hip moment and power than all other MSL phases. SAS (SAS Institute Inc., Carey, NC, USA) were used to conduct all statistical analyses and $p < 0.05$ was considered statistically significant unless otherwise noted.

For the analysis of MSL phase, three contrasts were conducted (pushback to each of other three phases) upon twelve variables (flexion and extension moment and power generated and absorbed for the ankle, knee, and hip). Thus, Bonferroni-adjusted values of $p < 0.00417$ were used for omnibus ANOVA significance and $p < 0.017$ were used for within-contrasts significance.

Multiple linear regressions were used to test the effects of age group and step length on kinematic and kinetic peaks. However, age group and step length could not be simultaneously included in a single multiple linear regression model because they have previously been shown to be correlated (Cho et al., 2004; Medell and Alexander, 2000; Schulz et al., 2007). To avoid potential distortion of results due to collinearity of the independent variables (Pedhazuer,

1997), four regression models were used to predict all dependent variables: First, two simple linear regression models were used to predict the independent effects of age group alone (model 1) and MSL alone (model 2). Then, two order-dependent multi-stage linear regression models (Pedhauzer, 1997) were employed where step length was added to the age group model (model 3) and age group added to the step length model (model 4). Models 1 and 2 enabled the determination of the variance explained by each independent variable alone, while models 3 and 4 were multistage regressions that enabled the determination the additional variance, if any, explained by the secondary variable. Dependent variables analyzed included stepping leg ankle, knee, and hip peak flexion and extension angle, velocity, and moment, as well as peak power generated and absorbed at each joint. Torso range of motion and flexion and extension angle and velocity were also considered. Since 29 variables were tested using these linear models, the Bonferroni-adjusted value of $p < 0.0017$ were considered statistically significant. Outlier data points were excluded from primary analysis generally if they were 2SD beyond the mean; these data are included and identified in all figures and tables for reference.

3. Results

3.1. Subject characteristics and step lengths

The young weighed less than the older women but were similar in height (Table 1). The young stepped farther than the older women (mean[SD] 77[5] and 55[8]% height or 125[9] and 88 [13] cm, respectively, $p < 0.0001$) and there was little or no overlap in the ranges of step lengths attained. Only one older subject ever stepped farther than the poorest-performing young subject, but when all acceptable step lengths were averaged into a single ensemble mean there was no overlap. The younger women all stepped beyond 69% height or 111 cm while the older women did not step beyond these thresholds.

3.2. Kinetic demands by MSL phase

Stepping leg plantarflexion, knee extension, and hip flexion moment, as well as power generated and absorbed were significantly greater during the pushback phase than during all other phases ($p < 0.017$, Fig. 2). Because of these data and because the pushback phase has been subjectively rated as the most difficult (Schulz et al., 2007), all subsequent analyses were restricted to the pushback phase.

3.3. Peak kinematics and kinematics during MSL pushback phase

Younger women used greater knee flexion moments and absorbed more power at their knee, regardless of step length. All subjects used greater torso extension velocities for longer steps, regardless of age. Aside from these exceptions, all torso, hip, and knee angle, velocity, moment, and power were significantly greater for both longer steps and younger subjects (Fig. 3 & 4, Table 2).

Significant additional variance in peak hip and torso flexion and extension velocities, hip extension moment, and hip power generated and absorbed were explained by step length after controlling for age group (Table 2).

The dynamometer-measured knee and hip extension speed, strength, and power capacities of these subjects have been reported previously (Schulz et al., 2007). The dynamometer apparatus used was not instrumented to take measurements at the ankle. Hip extension velocities, moments, and power generated during MSL exceeded the dynamometer-measured capacities of the younger women but not the older women (Fisher Exact $p = 0.01$). The knee extension velocities, moments, and powers used to perform these maximal-length steps were generally at or below the dynamometer-predicted maximums for all subjects.

3.3. Movement coordination and timing during MSL pushback phase

Younger women reached their peak knee extension moments earlier than the older women (Fig. 3). The timing of the peak of the knee extension moment was bimodal, with all but two of the older women reaching their peak knee extension after 80% of pushback and all but three of the younger women reaching their peak before 40%. Because of this non-normal distribution with no apparent relationship to step length, the Fisher Exact test was used to test if the peak moments occurred before or after 50% of the pushback cycle. This analysis showed that the young more often reached their peak knee extension moments in the first half of the pushback phase (Fisher Exact $p=0.03$) and that a corresponding trend was not present at the ankle or hip.

4. Discussion

The dual-contact with feet apart, or “pushback” phase, of the MSL was the most kinetically-demanding phase, thus supporting our first hypothesis. Within this phase, hip kinematic and kinetic peaks were greater for both larger steps and younger subjects, while knee flexion and power absorbed were only greater for younger subjects. Regarding the second hypothesis, the findings of order-dependent multistage regressions indicated that, in general, torso and hip kinematics and kinetics were significantly associated with step length even after controlling for age group; only knee kinetics were associated with age group alone. Older women utilized an altered pattern of knee moment and possibly power absorption that may indicate a fundamental difference in stepping behavior between younger and older women. No ankle-related variables reached significance.

4.1. Step phase

The low joint moments and powers during the pushoff and swingout phases of the MSL seem to contradict the high joint moments and powers recorded during comparable phases of an apparently similar lunge-like task: stepping to recover balance when released from a forward lean (Madigan, 2006; Wojcik et al., 2001). However, lean-release and MSL stepping are very different. In lean release stepping, the initial instability is provided by the lean angle and the subject has little time available for balance recovery before a safety harness stops their fall. In contrast, MSL steps are volitionally initiated to step as far as possible while still being able to return in a single step. In fact, each MSL phase shares characteristics with a comparable phase of the inverted pendulum model of gait. MSL pushoff exhibits a complete anticipatory postural adjustment as in gait initiation. The body pivots about the stance foot during MSL swing phases, exchanging kinetic and potential energy as in the swing phase of gait. During MSL pushback the stepping leg absorbs momentum after ground contact and supplies momentum to attain step liftoff. This is similar to the stance phase of gait, but while gait efficiently maintains forward progression, MSL pushback reverses the direction of progression with as large a step as possible.

4.2. Peak kinematics and kinematics during MSL pushback phase

Although the length and timing of perturbation-elicited steps (King et al., 2005; Wojcik et al., 1999), the timing of volitional steps (Lord and Fitzpatrick, 2001; Luchies et al., 2002), and the lower extremity strength required to recover from a forward fall (Madigan and Lloyd, 2005; Pijnappels et al., 2005a; Wojcik et al., 2001) have been quantified, we are not aware of published studies quantifying the lower limb strength and power used to perform volitional steps of maximal length.

Step length had no significant age-independent effect for knee flexion moment and power absorption, while torso and hip kinematics and kinetics, particularly velocities and power absorbed, were associated with step length even after controlling for age group. The increase in peak hip and torso kinematics and kinetics required for longer steps has important

implications for loss of function and the ability to recover from falls, as poor lower limb power may be more predictive of future falls (Skelton et al., 2002) and functional difficulty (Bassey et al., 1992; Skelton et al., 1994; Skelton et al., 2002) than more traditional measures of strength. The increase in peak hip extension moment with increasing step length for the volitional steps performed in this study mirrors the increase in peak hip extension moment required to recover balance with a single step when released from greater lean angles (Madigan and Lloyd, 2005). However, significant increases in ankle and knee moment were found for lean release recovery steps from greater lean angles, while these moments did not increase significantly with step length in our data due to our use of Bonferroni corrections. Furthermore, a related study (Madigan, 2006) found age-related reductions in joint power that we found to be more closely associated with step length. These discrepancies may be partially due to the exclusion of step length as a factor in these studies, but are more likely to be explained by the methodological differences between maximal length stepping and recovery from a lean release.

It is noteworthy that large plantarflexion moments were not required for MSL, considering that nearly quadruple the plantarflexion moment utilized by the young women in this study was utilized by similarly-aged women to recover from a trip (Pijnappels et al., 2005a). This discrepancy is most likely due to the time-critical nature of trip recovery and the powerful push-off and hip flexion reaction it requires, while the MSL pushoff evaluated here is voluntary and requires similar maximal hip flexion moment and power as that required to maintain steady-state gait (Riley et al., 2001).

The large difference in step length and lack of overlap between the younger and older subjects and presents a potential confound and complicated the analysis. Using the ensemble means of step length, no older subject stepped beyond 67% of her own height (110cm) and no younger subject stepped less than 69% of her height (111cm). In order to explore this potential confound between age group and step length, future investigations of the biomechanics of volitional stepping might compare submaximal steps of younger subjects to the maximal steps of older subjects.

The finding that the younger subjects often exceed a dynamometer-measured limit is noteworthy, but not unexpected. Dynamometer testing generally requires isolation of the joint being tested, which is problematic for the hip and may not accurately represent functional muscle usage and intersegmental power transmission during whole-body movements. This discrepancy between functional usage and clinical measurement leads to the possibility that a multi-joint dynamometer test or some other more functional assessment might be a more appropriate measure of real-world performance than single-joint measures of ability.

4.3. Movement coordination and timing during MSL pushback phase

While no significant differences were found in the magnitude of the peak knee extension moments between younger and older women, the young reached their peak knee extension moments shortly after step contact, while the knee was still flexing, while the old reached their peak just before the return step liftoff. This delay in peak knee extension moment may be an indication of a reduced ability of the elderly to rapidly apply force to the ground with their stepping leg in order to prevent an impending fall, particularly because the rapid application of knee extension moment during knee flexion is required by such tasks. Similarly, delayed support limb loading has been found to be associated with an inability to successfully recover from a trip (Pavol et al., 2001). Time to peak force has also been shown to be the best single predictor of lunge performance (Cronin et al., 2003) and may be as critical as the absolute force itself (Hakkinen, 1994; Tang and Woollacott, 1999). Delays in the onset of knee moment generation and reduced lower limb strength has been found to impair the ability to recover from trips in the elderly (Pijnappels et al., 2005b).

The age-related delay in peak knee extension moment identified here may initially appear to contradict recent findings of a consistent pattern of joint moments utilized by younger and older men to recover balance when released from a forward lean (Madigan and Lloyd, 2005), but they do not. We also found a consistent pattern of joint moments when the return step was omitted and the subject was only required to maintain the stepped out position, as in a lean-release balance recovery (data available from corresponding author upon request). However, when a return step was required the age-related delay in peak knee moment emerged.

There are several possible explanations for the delay in peak knee extension moment, one of which is greater musculotendon compliance of the older women. Elderly women have demonstrated a greater ability to store and use elastic energy of the knee extensors via the stretch shortening contraction (about $28\pm 7\%$) than elderly men (about $15\pm 4\%$) or even young men (about $20\pm 8\%$) or women (about $19\pm 4\%$) (Lindle et al., 1997). Since this effect was gender-specific, both men and women should be tested in future studies of stepping to evaluate possible gender-related effects. Another possible explanation for the delay in peak knee extension moment is an age-related alteration in the pattern of muscle activations used to perform large out-and-back steps, but this cannot be determined as electromyographic data were not recorded here. The relative weakness of older subjects, particularly at faster contraction velocities (Hortobagyi et al., 1995; Pousson et al., 2001; Schulz et al., 2007), also may play some role in this delay. Furthermore, the non-overlapping step length ranges reached by the young and old subjects leaves the possibility of some threshold effect for steps beyond 69% height that may require or lead to a different motor plan. Regardless of the root cause of the delay in peak knee extension moment in the elderly women, the apparent absence of concomitant effects of step length at the knee indicates that there exists a fundamental difference between younger and older women regarding when and how knee moment is generated during large volitional out-and-back steps that may also be present when arresting falls with a single large forward step. Additional data on muscle activations and forward dynamics modeling of the stepping task are required to determine the nature of this difference.

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Fig. 1. Side view (top) and top view (bottom) of testing setup and biomechanical linkage used. Joint centers indicated by filled black circles and segment centers of mass (foot, shank, thigh, and head-arms-torso) indicated by checkered circles.

Fig. 2.

Stepping leg joint kinetics during Maximum Step Length (MSL) by phase of movement. Data normalized to subject height (ht) in m and weight (wt) in N. "Pushoff" is prior to step out initiation, "swingout" is aerial phase during step out, "pushback" dual contact phase with feet apart, and "swingback" is aerial phase during return step. Plantarflexion is considered flexion of ankle. Outliers marked as points, but their inclusion or exclusion does not alter findings. Two outlier points for swingback phase hip power generated and absorbed at 1.23 and 1.12, respectively, not shown for scale. * indicates $p < 0.017$.

Fig. 3.

Hip (top row), knee (middle row), and ankle (bottom row) flexion angle, velocity, moment, and power (columns from left to right) profiles during “pushback” (dual contact with feet apart) phase of Maximum Step Length (MSL) for younger (solid line) and older (dashed line) women averaged across all subjects within each age group. Shaded area represents ± 1 SD. Time normalized to percentage of cycle such that step out ground contact occurs at 0 and return step liftoff occurs at 100. Kinetics normalized to subject height (ht) in m and weight (wt) in N.

Fig. 4.

Peak hip flexion and extension velocity (top), extension moment, and power generated and absorbed (bottom) during “pushback” (dual contact with feet apart) phase of Maximum Step Length plotted against step length. Torso velocities were similar to hip but smaller in magnitude. Outlier data point omitted in table 2 analysis filled. Step length normalized to subject height (ht) in m and kinetics normalized to ht and body weight (wt) in N.

Table 1

Mean [SD] subject characteristics and Maximum Step Length (MSL)

	Younger Women	Older Women
Number of subjects	11	10
Mean age (years) *	24 [3]	73 [5]
Height (cm)	163 [7]	160 [5]
Mass (kg) [†]	55.0 [5.1]	68.4 [14.1]
Body Mass Index (kg / m ²) [†]	20.7 [3.2]	26.7 [3.6]
MSL (% height) *	78.5 [5.4]	57.8 [9.1]

* indicates age group effect $p < 0.0001$

[†] indicates age group effect $p < 0.01$

Table 2

Linear regressions of peak ankle, knee, hip, and torso kinematics and kinetics on age group alone, step length alone, and step length after accounting for age group. Only variables with significant (bold indicates $p < 0.0017$) effects shown.

Property	Direction	Joint	Age Group Only		Step Length Only		Step Length added to Age Group (Type I SS)	
			p	R ²	p	R ²	p-Age Group	p-Step Length
Angle	Flexion	Knee	<0.0001	0.57	<0.0001	0.62	<0.0001	0.0621
		Hip	0.0001	0.54	<0.0001	0.70	<0.0001	0.0062
	Extension	Knee *	0.0463	0.19	0.0413	0.20	0.0501	0.5135
		Knee *	0.0004	0.51	0.0007	0.48	0.0005	0.3501
Velocity	Flexion	Torso	0.0010	0.44	<0.0001	0.58	0.0004	0.0243
		Knee	0.0003	0.52	<0.0001	0.65	0.0001	0.0205
	Extension	Hip	0.0007	0.48	<0.0001	0.79	<0.0001	<0.0001
		Torso	<0.0001	0.60	<0.0001	0.83	<0.0001	0.0002
Moment	Flexion	Knee *	0.0024	0.41	<0.0001	0.62	0.0005	0.0065
		Knee *	0.0013	0.47	0.0003	0.54	0.0009	0.0982
	Extension	Hip	0.0001	0.58	<0.0001	0.82	<0.0001	0.0002
		Torso	0.0132	0.28	<0.0001	0.59	0.0012	0.0003
Power	Flexion	Knee	0.0003	0.51	0.0023	0.39	0.0004	0.8447
		Hip	<0.0001	0.65	<0.0001	0.61	<0.0001	0.227
	Extension	Hip *	<0.0001	0.61	<0.0001	0.69	<0.0001	0.0228
		Hip	<0.0001	0.80	<0.0001	0.86	<0.0001	0.0006
Power	Absorbed	Knee *	0.0056	0.35	0.0044	0.37	0.0059	0.3215
		Knee *	<0.0001	0.62	0.0022	0.43	0.0001	0.6467
	Generated	Hip	<0.0001	0.69	<0.0001	0.90	<0.0001	<0.0001
		Hip	<0.0001	0.81	<0.0001	0.86	<0.0001	0.0008

* indicates outlier data point for an older subject omitted from analysis