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Gender differences in offaxis neuromuscular control during stepping under a slippery condition

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Abstract

Purpose: Females are at greater risks of musculoskeletal injuries than males, which may be related to decreased neuromuscular control in axial and/or frontal planes, *offaxis neuromuscular control*. The objective of this study was to investigate gender differences in offaxis neuromuscular control during stepping under a slippery condition.

Methods: Forty-three healthy subjects (21 males and 22 females) performed different stepping tasks under a slippery condition, namely free pivoting task (FPT) to control axial plane pivoting, free sliding task (FST) to control frontal plane sliding, and free pivoting and sliding task (FPST) to control axial pivoting and frontal sliding on a custom-made offaxis elliptical trainer.

Results: Compared to males, females showed significantly higher pivoting instability, higher max internal and external pivoting angles, higher mean max medial and lateral sliding distance, and higher entropy of time to peak EMG in the medial and lateral gastrocnemius muscles during the FPST and higher entropy of time to peak EMG in the lateral gastrocnemius muscle during the FPT and FST.

Conclusions: The findings may help us understand potential injury risk factors associated with gender differences and provide a basis for developing targeted neuromuscular training to improve offaxis neuromuscular control and reduce musculoskeletal injuries associated with excessive offaxis loadings.

Keywords

Gender; slippery condition; offaxis neuromuscular control; musculoskeletal injuries; risk factors

Introduction

Females are at greater risks of musculoskeletal injuries of lower limbs than males (Arendt and Dick 1995). The gender differences in injury rates such as females being at 2-9 times

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Conflict of Interest Li-Qun Zhang and Yupeng Ren hold equity positions in Rehabtek LLC, which is involved in developing the multi-axis robotic elliptical trainer in this study.

Ethical standards All participants gave their written informed consent to participate in the study that was approved by the Institute of Review Board at Northwestern University.

higher rate of ACL injuries than males are believed to be partially explained by anatomical and neuromechanical properties such as wider pelvis-to-femoral length ratios (Horton and Hall 1989), narrower intercondylar notch (Charlton et al. 2002), greater joint laxity (Park et al. 2008), greater axial, frontal, or axial and frontal plane knee movements (*offaxis* movements) (Quatman and Hewett 2009), more extended knee postures (Quatman and Hewett 2009), higher quadriceps to hamstring ratio, and imbalance of medial and lateral gastrocnemius activities (Landry et al. 2007a, b; Myer et al. 2009; Withrow et al. 2008). Especially, knee injuries are closely related to excessive loadings in the non-sagittal planes including transverse and frontal planes although major motion of the knee is in sagittal plane (Ren et al. 2013). Thus, better physiological abilities of controlling offaxis movements, *offaxis neuromuscular control* can potentially reduce chances of causing excess loading on the knee and consequently reduce musculoskeletal injuries such as ACL injuries (Hewett et al. 2007; Lee et al. 2011; Quatman et al. 2010).

Neuromuscular control requires complex interactions between the nervous and musculoskeletal systems (Enoka 2002; Williams et al. 2001). Considering that the human knee is a complex joint with demonstrating plane dependent properties in sagittal, frontal, and transverse planes (Zhang and Wang 2001), investigating offaxis neuromuscular control in frontal and/or transverse plane during strenuous and functional tasks might provide us insights into understanding potential injury risk factors associated with gender differences. Previous studies suggested that a slippery walkway is challenging for even healthy individuals and highly related to falling and sport-related injuries (Cappellini et al. 2010; Redfern et al. 2001). Yet, it remains unclear whether gender differences in offaxis neuromuscular control can be presented during strenuous activities such as the tasks when subjects control multiaxis movements including simultaneous sagittal stepping, axial plane pivoting and frontal plane sliding movements under a slippery condition.

The objective of this study was to investigate gender differences in offaxis neuromuscular control in terms of endpoint kinematics, instability, entropy of time to peak EMG in lower limb muscles, and stepping speed, of healthy subjects who needed to control offaxis movements during stepping under a slippery condition. The hypotheses were that compared to males, females showed higher pivoting instability, higher max external and internal pivoting angles, higher sliding instability, higher max medial and lateral sliding distances, and higher entropy of time to peak EMG at each muscle when they controlled multiaxis movements. Findings from this study may help understand gender differences in injury risk factors and develop more effective training programs to reduce lower limb injuries associated with offaxis loadings such as ACL injuries.

Methods

Subjects

Forty-three subjects without any lower-limb musculoskeletal injury participated in the study. All the subjects gave a written informed consent approved by the Institute of Review Board at Northwestern University. Twenty-one subjects were males and the other twenty-two subjects were females. The subject information is provided in Table 1.

Experimental Setup

Gender differences in offaxis neuromuscular control were investigated using a custom-made offaxis ET (Geiger 2008; Ren et al. 2008). As shown in Fig. 1, a conventional elliptical trainer was modified to allow multi-degree of freedom movements including axial plane pivoting and frontal plane sliding during sagittal stepping. The offaxis training system can produce various stimuli to each foot via servomotor controls with real-time audio-visual

biofeedback of pivoting angle and sliding distances (Fig. 1). On the offaxis elliptical trainer, each subjects' leg was aligned with the center of the pivoting axis on each footplate and their each foot was fixed with a pair of toe and heel straps, so that their feet and the footplates rotated together (Ren et al. 2013). The system measured pivoting torque, sliding force, and pivoting and sliding positions of the footplates. The offaxis trainer used two computers; one displayed the real-time visual biofeedback, and the other controlled the offaxis trainer to produce slippery conditions via friction compensation control so that the footplates were free to pivot and/or slide (Fig. 1a) (Ren et al. 2013). A potentiometer was attached to the wheel sliding on the ramp of the elliptical trainer to measure stepping cycles of the offaxis elliptical trainer.

Protocol

Prior to the actual tasks, all subjects stepped on the ET at their comfortable speed for few minutes to be familiar with the ET with the pivoting and sliding mechanisms locked. Then, subjects were asked to perform stepping tasks on the offaxis ET to assess offaxis neuromuscular control, aiming at how well subjects maintained the second toe pointing forward in pivoting and/or the initial medio-lateral position in sliding during sagittal stepping when the footplates were free to pivot and/or slide. In a regular stepping task (RST), subjects were asked to step forward with the pivoting and sliding mechanisms locked. In a free pivoting task (FPT), subjects were asked to maintain the second toe pointing forward position indicated by the center target position in pivoting (Fig. 1b) during stepping when the footplates were free to pivot. In a free sliding task (FST), subjects were asked to maintain each foot at the initial medio-lateral position as indicated by the center target position in sliding (Fig. 1b) during stepping when the footplates were free to slide. In a free pivoting and sliding task (FPST), subjects were asked to maintain the foot at the target positions during stepping when the footplates were free to pivot and slide. It should be noted that there were a motor internal pivoting task (MIPT) and a motor external pivoting task (MEPT) between the FPT and the FST in which subjects were asked to maintain the second toe pointing forward position during stepping with internal pivoting and external pivoting perturbation to feet, respectively. Because the objective of this study was to compare gender differences in offaxis neuromuscular control during stepping under a slippery condition, the results of the MIPT and MEPT were not reported in this study. During each task, the subjects were asked to step at their comfortable speed for a minute. Rest periods between tasks were given to minimize potential fatigue. Subjects received real-time audio-visual feedback from the computer screen to guide them during the task (Fig. 1b). If foot positions were out of the specified range (Fig. 1b), they would hear a beeping sound. During stepping, all subjects were asked to wear a safety harness and hold the handle bar on the front of the ET for safety and for reducing the influence of upper limb movements on the tasks (Ren et al. 2013). During each task, muscle activities were recorded from the Biceps Femoris (BF), Semitendinosus (ST), Medial Gastrocnemius (MG), Lateral Gastrocnemius (LG), Vastus Medius Obliquus (VMO), Vastus Lateralis (VL), Gluteus Maximus (Glmax), and Glutues Medius (Glmed) on the right leg using a Bagnoli-8 EMG system (Delsys, Boston, MA). All internal and external pivoting angles, medial and lateral sliding distances, elliptical stepping cycle, and EMG data were recorded via a data acquisition system (National InstrumentsTM, Austin, TX) with Labview at 1000 Hz.

Data analysis

Instability—Pivoting instability was quantified by the standard deviation of pivoting angles from the target position for a minute during the free pivoting task (FPT) and during the free pivoting and sliding task (FPST) (Ren et al. 2013). Higher pivoting instability means that subjects did not control their legs well in pivoting during stepping. Similarly, sliding instability was quantified by the standard deviation of sliding movements from the

target position for a minute during the free sliding task (FST) and during the pivoting and sliding task (FPST). Higher sliding instability means that subjects did not control their legs well in sliding during stepping.

Temporal Parameter and kinematics of the footplates—Pivoting angle, sliding distance, and EMGs from each task were segmented into individual stepping cycles based on the time intervals of successive events when the same footplate reached the most anterior position from the potentiometer signal, similar to gait analysis (Lee and Hidler 2008). Then, the segmented data were re-sampled and time-normalized in terms of the stepping cycle (0-100%) (Lee and Hidler 2008). Stepping speeds in revolution per minute (RPM) were computed based on the time intervals of successive events when the same footplate reached the most anterior position. Mean stepping speed was computed for each person and each task. Loading phase in % of stepping cycle were also computed based on the period from when a footplate reached the most anterior position to when the same footplate reached the most posterior position (Lu et al. 2007). The mean loading phase was computed for each person per task. Because subjects can maintain their target position well at some cycles but not at other cycles, maximum and mean maximum external and internal pivoting angles across all the stepping cycles were computed at the free pivoting task (FPT) and the free pivoting and sliding task (FPST). Similarly, maximum and mean maximum medial and lateral sliding distances were computed at the free sliding task (FST) and the free pivoting and sliding task (FPST).

EMG entropy—Entropy is a measure to quantify highly variable subject's neuromuscular performance and understand uncertainty of neuromuscular system in selecting joint motions or muscle activities for given tasks (Cavanaugh et al. 2005; Kurz and Stergiou 2003; Rieke et al. 1999; Tononi et al. 1998). Specifically, time to peak EMGs in lower limb muscles are closely related to lower limb coordination and potential injury risk factors during the accomplishment of physical tasks (Hewett et al. 2007). Thus, entropy of time to peak EMG in the aforementioned muscles was investigated. For each task, to determine entropy of the time to peak EMG, raw EMGs of the investigated muscles were rectified and EMG linear envelope (LE) was created using zero-delay 6th order Butterworth filter with a cut-off frequency of 7Hz. The EMG LE was segmented and time-normalized to express the data in 0-100% of stepping cycle as mentioned above. Then, time to peak EMG was identified at each cycle for each person, each task, and each muscle, and probability of each bin (bin width: 5% of the stepping cycle) for each person, each task, and each muscle was computed as $P_d = n/T$ where P_d was the discrete probability of the time to peak EMG in bin d , n was the number of times when the time to peak EMG in the d bin was repeated, T was the number of the total discrete states observed in each muscle (Kurz and Stergiou 2003). The bin width was determined based on functionally meaningful discrete states on a conventional elliptical trainer (Burnfield et al. 2010). Then, entropy of time to peak EMG, was computed as (1)

$$H = - \sum_{d=1}^d P_d \log_2 (P_d) \quad (1)$$

Based on this equation, a small entropy value indicates greater certainty and a larger value indicates lower certainty of selecting a time to peak EMG during tasks.

Statistical Analysis

Normality of each dependent variable was checked through Skewness and Kurtosis tests (Jarque and Bera 1987), then independent t-test or Mann-Whitney U test was applied to compare gender differences in the aforementioned kinematics, temporal parameters, and entropy of time to peak EMG at each muscle during each offaxis task (i.e. FPT, FST, and

FPST). Paired t-test or Wilcoxon test were applied to compare task differences in the temporal parameters and entropy of time to peak EMG at each muscle between each offaxis tasks and the regular stepping task. The significant level was set at 0.05. All statistical tests were conducted using STATA 12.

Results

Temporal Parameters

No statistically significant difference in mean stepping speed and mean loading phase at each task were found between genders. The subjects stepped slower during the free pivoting task (FPT) and the free pivoting and sliding task (FPST) compared to the regular stepping task (RST) ($p=0.0001$ and $p=0.0017$ respectively; see Table 2). However, there was no significant difference between the free sliding task (FST) and the regular stepping task (RST). There was no significant difference in loading phase at all other tasks compared to the RST.

Kinematics

During the FPST, females showed significantly higher maximum external and internal pivoting angles than males ($p=0.0246$ and $p=0.0203$ respectively; see Fig. 2a and b) but not during the FPT (Fig. 2). Furthermore, during the FPST, females showed higher pivoting instability than males ($p=0.0491$; see Fig. 3).

Mean maximum lateral and medial sliding distances were significantly different between males and females ($p=0.0335$ and $p=0.0279$ respectively) during the FPST but not during the FST (Fig. 4c and d). No gender difference was found in sliding instability (Fig. 5).

Muscle Activation

Compared to males, females showed significantly higher entropy of time to peak EMG specifically in the lateral gastrocnemius (LG) during the FPT, the FST, and the FPST ($p=0.028$, $p=0.0345$ and $p=0.0145$ respectively), the medial gastrocnemius (MG) during the FPST ($p=0.0168$), and marginally significant entropy of time to peak EMG in the vastus lateralis (VL) during the FST and the FPST ($p=0.054$ and $p=0.0582$ respectively, Table 3).

Compared to the Regular Stepping Task (RST), subjects showed significantly higher entropy of time to peak EMG in most of the muscles during all offaxis tasks (i.e. the FPT, FST, and FPST). Specifically, significantly higher entropy of time to peak EMG was found in the MG ($p<0.0001$ and $p<0.0001$ respectively), LG ($p<0.0001$ and $p<0.0001$ respectively), vastus medialis oblique (VMO, $p=0.0001$ and $p=0.0001$ respectively), VL ($p=0.0010$ and $p<0.0001$ respectively), gluteus maximus (Glmax, $p<0.0001$ and $p=0.0003$ respectively), and gluteus medius (Glmed, $p<0.0001$ and $p<0.0001$ respectively; Table 4) during the FPT and the FPST, and the biceps femoris (BF, $p=0.0121$) during the FPT. During the FST, significantly higher entropy of time to peak EMG was found in all muscles (BF $p=0.0070$, MG $p<0.0001$, ST $p=0.0156$, LG $p<0.0001$, VMO $p<0.0001$, VL $p<0.0001$, Glmax $p=0.0001$, and Glmed $p<0.0001$).

Discussion

This study investigated gender differences in offaxis neuromuscular control during multi-axis movements under a slippery condition. A unique feature of the experimental setup was that potential injury-causing situations were created using the offaxis elliptical trainer. Our results suggested that compared to males, females showed decreased offaxis neuromuscular control when they needed to control multi-axis movements, which may be related to females

being at a higher risk of musculoskeletal injuries such as ACL injuries. Furthermore, compared to the regular stepping task, offaxis tasks under a slippery condition were able to alter muscle activities in terms of higher entropy of time to peak EMG in most measured muscles.

It was found that compared to males, females showed higher max internal and external pivoting movements and higher pivoting instability during more challenging offaxis tasks, which required subjects to control multiaxis movements (e.g. the FPST). However, no gender differences in kinematics were found during the less challenging FPT. Similarly, compared to males, females showed significantly higher mean max medial and lateral sliding distances during the FPST, but no gender differences in kinematics were found during the FST. It should be noted that the present findings still held true when comparing typical data from males and females with similar height, indicating the aforementioned gender differences were not significantly associated with the gender difference in height. Strong and growing evidence of musculoskeletal injury mechanisms involving multiaxis movements in combined sagittal, frontal, and axial planes supports our findings in regards to gender differences in offaxis neuromuscular control as potential injury risk factors (Boden et al. 2000; Quatman and Hewett 2009). Increased valgus loading and movements are potentially associated with an increased risk of ACL injuries based on video studies and in vivo studies of ACL injuries (Boden et al. 2000; Quatman and Hewett 2009). Increased valgus loading and movements do not always indicate pure frontal plane movements and often involve axial plane movements such as internal or external rotation (i.e. multiaxis movements) (Quatman and Hewett 2009; Quatman et al. 2010). In a video analysis study among Norwegian basketball players, more than 50% of females demonstrated a valgus knee collapse during the injury event, while 20% of men showed the valgus knee collapse (Krosshaug et al. 2007). Previous studies also reported that females demonstrated higher valgus angles than males during side-cutting tasks (Hewett et al. 2007). Furthermore, females exhibited greater peak tibial internal rotation than males during jump-landing tasks (Padua et al. 2005), greater femoral internal and tibial external rotation after landing compared to males (Hewett et al. 2007), and larger mean variability in internal and external tibial rotation (McLean et al. 2005). Clinical imaging studies stated that valgus collapse probably occurred during ACL injuries (Quatman and Hewett 2009). If ACL injuries mainly occur due to major axis movements (flexion/extension movements), then bone bruises would be located at the medial tibial plateau (Quatman and Hewett 2009). However, magnetic resonance imaging showed that after acute ACL injuries, 80% of bone bruises were found in posterolateral portions of the tibial plateau or in the lateral femoral condyle (Quatman and Hewett 2009; Sanders et al. 2000). Moreover, in recent simulation studies (Oh et al. 2012; Shin et al. 2011), combined knee valgus and internal rotation moments increased ACL strain more than internal rotation moment alone. All these previous findings support the involvement of multiaxis movements at the time of musculoskeletal injuries such as ACL injuries.

In addition, compared to males, females showed significantly higher entropy of time to peak EMG in the gastrocnemius muscles, especially lateral gastrocnemius during all offaxis tasks and marginally higher entropy of time to peak EMG in vastus lateralis during the FST and FPST. Our finding of higher entropy in time to peak EMG in proximal and distal muscles in females may indicate females being at a greater risk of musculoskeletal injuries and be supported by previous studies of gender specific neuromuscular strategies such as muscle activation patterns in proximal, anterior-posterior, medial-lateral, and distal muscles (Hewett et al. 2007). In previous studies, females showed increased hip internal rotation during landing and difficulties to control gluteal muscles and relied more on the quadriceps muscles during single-leg squatting, which could potentially increase the risk of ACL injuries (Lephart et al. 2002; Zeller et al. 2003). Co-contraction of anterior-posterior muscles such as

quadriceps and hamstring may protect the ACL against anterior drawer (Hewett et al. 2007). Therefore, decreased hamstring to quadriceps activation ratio or greater quadriceps activities in females compared to males (Hewett et al. 2007) may cause higher relative load on the ACL in females compared to males (Padua et al. 2005). Furthermore, females also demonstrated a decreased ratio of medial to lateral quadriceps activation compared to males, which could potentially compress the lateral joint, and increase anterior shear force loading on the ACL (Markolf et al. 1995). Distal muscle activations such as ankle and calf muscles may play an important role in knee joint stability (Hewett et al. 2007). Previous studies showed that gastrocnemius activation in a static situation could increase ACL strain when the knee was nearly extended (Fleming BC et al. 2001). In other studies, elite female soccer players showed a higher gastrocnemius activity and a mediolateral gastrocnemius activation imbalance during early stance to mid-stance of the side-cut and during both run and cross-cut maneuvers. Male players did not show such patterns (Landry et al. 2007a, b).

While males demonstrated lower max external pivoting angle in the FPST compared to the FPT, female demonstrated higher max external pivoting angle in the FPST compared to the FPT, which led to significant gender differences in max external pivoting angle in the FPST. Furthermore, while no sex differences were found in sliding instability in both FST and FPST, both males and females demonstrated lower mean max lateral sliding distance in the FPST compared to the FST, but the magnitude of reduction in mean max lateral sliding distance in the FPST in males were larger than that in females, which resulted in significant gender differences in mean max lateral sliding distance in the FPST. Females may demonstrate decreased neuromuscular control compared to males during multiaxis movements, which might be related to higher uncertainty of activating gastrocnemius muscles, especially lateral gastrocnemius muscles during multiaxis movements. Furthermore, performing the FPST might utilize independent neuromuscular control strategies that might be different from that of the FPT and the FST (Choi and Bastian 2007). Compared to the FPT or the FST, adding additional degree of freedom in the FPST might have helped individuals to choose more flexible neuromuscular control strategies (Shull et al. 2013) to maintain the targeted positions, which may have expressed as decreased offaxis neuromuscular control in females compared to males during the FPST. From this study, detailed underlying mechanisms of decreased offaxis neuromuscular control in females compared to males during multiaxis movements are not clear. Further study might be necessary to understand the detailed underlying mechanisms.

Conclusions

Up to best of the authors' knowledge, this is the first study to investigate gender differences in physiological abilities of controlling multiaxis movements under a slippery condition, which is related to injury related scenario. Compared to males, females demonstrated decreased offaxis neuromuscular control in terms of higher pivoting instability, higher max internal and external pivoting angle, higher mean max medial and lateral sliding distance, and higher entropy of time to peak EMG in the medial and lateral gastrocnemius muscles. Decreased offaxis neuromuscular control in females during multiaxis movements compared to males could lead to higher susceptibility of musculoskeletal injuries such as ACL injuries. The findings from this study may help understand potential injury risk factors contributing to musculoskeletal injuries such as ACL injuries. Furthermore, based on the findings of this study, subject-specific or gender-specific neuromuscular training under potential injury causing situations may benefit both genders and reduce musculoskeletal injuries including ACL injury.

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Fig. 1.

a The offaxis elliptical trainer allowing pivoting and sliding movements in left and right legs with slippery footplates via cable driven mechanisms including servomotors, cable, encoders, torque sensors, and footplates. **b** Visual Feedback for controlling pivoting and sliding directions of movements. Subjects were asked to maintain middle positions corresponding to the initial standing positions of foot at each plane (pivoting: axial plane, sliding: frontal plane).

Fig. 2. **a** Maximum External Pivoting Angle, **b** Maximum Internal Pivoting Angle, **c** Mean Maximum External Pivoting Angle, **d** Mean Maximum Internal Pivoting Angle in degree during the free pivoting task (FPT) and the free pivoting and sliding task (FPST) between males (black bar) and females (grey bar). Each bar with error bar plot indicates mean with 1SD from each task at each group. * indicates $p < 0.05$ between males and females at each task.

Fig. 3. Pivoting instability during the free pivoting task (FPT) and the free pivoting and sliding task (FPST) between males (black bar) and females (grey bar). Each bar with error bar plot indicates mean with 1SD from each task at each group. * indicates $p < 0.05$ between males and females at each task.

Fig. 4.

a Maximum Lateral Sliding, **b** Maximum Medial Sliding, **c** Mean Maximum Lateral Sliding, and **d** Mean Maximum Medial Sliding in mm during the free sliding (FST) and free pivoting and sliding task (FPST) between males (black bar) and females (grey bar). Each bar with error bar plot indicates mean with 1SD from each task at each group. * indicates $p < 0.05$ between males and females at each task.

Fig. 5. Sliding instability during the free sliding task (FST) and the free pivoting and sliding task (FPST) between males (black bar) and females (grey bar). Each bar with error bar plot indicates mean with 1SD from each task at each group.

Table 1

Subject characteristics between males and females.

	Male	Female	P value
Age (years old)	25.0 (3.7)	24.5 (3.6)	0.68
Weight (Kg)	77.0 (11.4)	59.4 (7.8) ***	<0.001
Height (Cm)	178.8 (6.0)	165.1 (8.2) ***	<0.001
BMI (Kg/ m ²)	24.1 (3.4)	21.8 (2.3) *	0.019
Q angle (Deg)	10.1 (3.4)	13.5 (2.6) **	0.001
Physical activity level	2.9 (1.5)	2.5(1.6)	0.34

Values are means (1 SD). Q angle was measured with a goniometer as an angle between the line connecting the Anterior-Superior-Iliac-Crest (ASIS) to the center of patella and the line connecting the center of patella to the tibial tubercle in a supine and fully extended knee position (Aglietti et al. 1983), then averaged Q angle from the left and right leg was reported. Physical activity levels were counted based on the custom-made survey as 0 points for “did not do regular physical activities”, 1 points for “did once a week recreational sport”, 2 points for “did once a week strenuous/competitive sport”, 3 points for “did twice a week strenuous/competitive sports”, 4 points for “did three to four times a week strenuous/competitive sports”, and 5 points for “I am a semi-professional sportsman (Geiger 2008).”

* indicates p<0.05

** indicates p<0.01

*** indicates p<0.001 between males and females.

Table 2

Stepping speed and loading phase between tasks

	Regular Stepping	Free Pivoting	Free Sliding	Free Pivoting and Sliding
Stepping	47.1 (7.9)	39.5 (9.2) ***	43.9 (9.7)	40.9(9.6) **
Speed(RPM) loading phase(%)	48.6 (1.1)	48.8 (2.2)	48.9 (1.7)	49.0 (1.8)

Values are mean (1 SD) at the regular stepping task (RST), the free pivoting task (FPT), the free sliding task (FST), and the free pivoting and sliding task (FPST).

** indicates $p < 0.01$

*** indicates $p < 0.001$ between the RST and the FPT, between the RST and the FST, or between the RST and the FPST.

Table 3

Entropy of time to peak EMG in leg muscles between 1 males and females at each task

	Regular Stepping		Free Pivoting		Free Sliding		Free Pivoting and Sliding	
	Male	Female	Male	Female	Male	Female	Male	Female
BF	2.63(0.42)	2.70(0.47)	2.83(0.36)	2.77(0.41)	2.82(0.41)	2.98(0.48)	2.73(0.38)	2.78(0.39)
MG	1.95(0.84)	2.07(0.72)	2.67(0.72)	2.74(0.60)	2.73(0.68)	3.02(0.73)	2.72(0.63)	3.19(0.62) *
ST	2.70(0.74)	2.73(0.50)	2.70(0.47)	2.86(0.39)	2.89(0.55)	3.10(0.45)	2.67(0.41)	2.73(0.48)
LG	2.18(0.74)	2.43(0.85)	2.70(0.48)	3.06(0.55) *	2.71(0.54)	3.08(0.58) *	2.66(0.65)	3.15(0.61) *
VMO	2.34(0.58)	2.45(0.58)	2.65(0.67)	2.74(0.53)	2.79(0.49)	2.92(0.45)	2.70(0.46)	2.83(0.38)
VL	2.48(0.52)	2.42(0.51)	2.67(0.33)	2.70(0.39)	2.84(0.30)	3.05(0.38)~	2.77(0.30)	2.96(0.35)~
Glmax	2.29(0.31)	2.36(0.52)	2.80(0.34)	2.66(0.38)	2.68(0.39)	2.68(0.38)	2.71(0.45)	2.68(0.45)
Glmed	2.38(0.32)	2.44(0.52)	2.75(0.37)	2.81(0.44)	2.79(0.56)	2.78(0.49)	2.80(0.49)	2.85(0.35)

Values are means (1 SD) of the BF, MG ,ST ,LG ,VMO ,VL , Glmax, and Glmed at each task, namely the regular stepping, the free pivoting, the free sliding, and the free pivoting and sliding task.

~ p<0.06

* indicates p<0.05

** indicates p<0.01

*** indicates p<0.001 between males and females at each task.

Table 4

Entropy of time to peak EMG 1 in leg muscles between tasks

	Regular Stepping	Free Pivoting	Free Sliding	Free Pivoting and Sliding
BF	2.67 (0.44)	2.80 (0.38) *	2.90(0.45) **	2.76(0.38)
MG	2.01 (0.77)	2.71 (0.65) ***	2.88 (0.71) ***	2.96 (0.66) ***
ST	2.72 (0.62)	2.78 (0.43)	3.00 (0.51) *	2.70 (0.44)
LG	2.31 (0.80)	2.88 (0.54) ***	2.90 (0.58) ***	2.91 (0.67) ***
VMO	2.39 (0.58)	2.70 (0.60) ***	2.86 (0.47) ***	2.77 (0.42) ***
VL	2.45 (0.51)	2.68 (0.36) **	2.95 (0.36) ***	2.87 (0.34) ***
GImax	2.33 (0.43)	2.73 (0.36) ***	2.68 (0.38) ***	2.69 (0.44) ***
GImed	2.41 (0.43)	2.78 (0.40) ***	2.78 (0.51) ***	2.83 (0.42) ***

Values are means (1 SD) of the BF, MG ST, LG, VMO, VL, GImax, and GImed) at each task, namely the regular stepping (RST), the free pivoting (FPT), the free sliding (FST), and the free pivoting and sliding task (FPST).

* indicates $p < 0.05$

** indicates $p < 0.01$

*** indicates $p < 0.001$ between the RST and the FPT, between the RST and the FST, or between the RST and the FPST.