Comprehensive gait analysis of healthy older adults who have undergone long-distance walking

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Abstract

Many older adults do not adhere to the recommended physical activity levels. This study examines the gait changes upon long-distance walking among healthy older adults. Gait tests of 24 adults aged 65 or more were conducted at the baseline, at the end of 30 and 60 minutes of treadmill walk. Spatial temporal, kinematic and kinetic gait data were computed. Perceived level of exertion was evaluated for each subject. Ten subjects (Group B) perceived higher exertion level than the remaining fourteen subjects (Group A). After walking, group B had significant reductions in dominant-side ankle joint range of motion and power, suggesting lower-leg muscle fatigue, which appeared to be compensated by significantly increased non-dominant side knee and hip motions. These changes were not observed in Group A. Differences in gait parameters between Group A and B implied that some biomechanical factors might contribute to the lack of walking of some older adults.

Keywords: Gait, Older Adults, Long-distance Walking, Perceived Exertion

Comprehensive Gait Analysis of Healthy Older Adults Who Have Undergone Long-distance Walking

Physical activity has positive effects on the health and well-being of older adults. Regular physical activity can protect against loss of functional ability(Laukkanen, Kauppinen, & Heikkinen, 1998), improve balance and stability (Melzer, Benjuya, & Kaplanski, 2003) , increase aerobic strength (Nelson et al., 2007) and decrease the risk of non-communicable diseases (Lee et al., 2012). Walking is one of the most effective modes of physical activity, particularly appropriate to the older population (Wong, Wong, Pang, Azizah, & Dass, 2003). Walking for more than one hour per day largely reduces the risk of disability (Boyle, Buchman, Wilson, Bienias, & Bennett, 2007) and mortality (Landi et al., 2008) among older adults.

Despite the proven health benefits, many older adults who were apparently healthy walked an average of less than 3,500 steps per day (Tudor-Locke et al., 2004), which was less than accumulated 30 minutes of walking per day. Lack of motivation has been considered the most common and prominent reason for the sedentary lifestyle (Moschny, Platen, Klaaßen-Mielke, Trampisch, & Hinrichs, 2011),(André & Dishman, 2012). However, one study indicated this could only explain 37% of the variance in intention to engage in physical activity between active and inactive people (Rhodes, Blanchard, Matheson, & Coble, 2006).

Biomechanical factors could also play an important role in maintaining regular walking. Aging is associated with significant reduction of muscle strength (Vandervoort, 2002), which impairs gait (Ko, Hausdorff, & Ferrucci, 2010). Differences in gait patterns between older and young adults have been revealed in previous studies (Watelain, Barbier, Allard, Thevenon, & Angué, 2000), (Cofré, Lythgo, Morgan, & Galea, 2011). Najafi et al. (Najafi, Helbostad, Moe-Nilssen, Zijlstra, & Aminian, 2009) reported the changes in gait patterns upon walking longer distances of older adults. They found significant increases in stride velocity and decrease in gait cycle time after the walk. However, their study confined a maximum walking distance of 20-meter, which was completed in almost one minute. Gait changes in healthy young subjects (Stolwijk, Duysens, Louwerens, & Keijsers, 2010) and lower-limb amputees (Yeung, Leung, Zhang, & Lee, 2013), (Yeung, Leung, Zhang, & LEE), who have walked over one hour, has been analyzed, and the findings helped identify some biomechanical reasons which might deter their long-distance walking.

Previous studies showed that gait analysis could aid in understanding the cause of difficulty in walking and treatment decision-making (Davis, Õunpuu, DeLuca, & Romness, 1999). While it was documented that older adults walked significantly less than the younger age groups of people (Tudor-Locke, et al., 2004), there is a lack of understanding of the their gait when they walk long distances.

This study aimed to 1) identify the changes in gait patterns among healthy adults aged 65 or more over long-distance walking and 2) investigate if older adults with different perceived level of exertion during long-distance have different gait patterns. The findings of this study could potentially reveal the biomechanical reasons for the lack of walking among healthy adults aged 65 or more. This forms a theoretical basis for the development of interventions to facilitate long-distance walk of older adults, which was evidenced by previous studies to be to be able to provide tremendous health benefits such as reduced risk of disability (Boyle, Buchman, Wilson, Bienias, & Bennett, 2007) and mortality (Landi et al., 2008).

Method

Participants

Convenience sampling was used to obtain a sample of 28 subjects aged 65 or more (19 males and 9 females) from the authors' university. Subjects should be aged over 65-year old, living in a community-based setting, and capable of ambulation without any walking aids. They should not have any cardiovascular or pulmonary diseases, cancer, uncontrolled hypertension, history of fall in the past year, diabetes, lower-limb pain or deformities that affect walking. Ethical approval was acquired from the university's Human Subject Ethic Sub-committee. Informed consent was obtained from all the participating subjects.

Experimental Procedures

Subjects walked on a treadmill without holding the handrails with self-selected speeds for two consecutive walking sessions of 30 minutes. The self-selected walking speed was achieved by allowing the subjects to change the speed of the treadmill according to their perceived level of comfort. They could stop the treadmill walking at any time they requested. Gait analysis and subjective assessments were conducted (1) before the treadmill walking, (2) after the 1st 30-minute and 3) after the 2nd 30-minute session of treadmill walking. Subjects walked in self-selected comfortable speed in both treadmill walking and gait analysis. Previous studies indicated that controlling the speed of walk could artificially alter gait patterns. (Jordan, Challis, & Newell, 2007). Self-paced treadmill walking was also found to be a reliable method to simulate the over-ground walking with self-selected speed (Plotnik et al., 2015).

Subjective Assessment

Subjects were required to provide a score (allowing decimals in any numbers) based on a Borg CR10 scale (Borg, 1982) (Figure 1) to reveal the degree of perceived exertion before and after each session of treadmill walking. The scores were then rounded up to one decimal place. In addition, each subject was asked a yes/no question "Does this level of exertion normally cause you to stop and take a rest?" at the end of the 1st 30-minutes of treadmill walking. Subjects who answered with "No" were assigned to Group A. Subjects with a "Yes" answer were assigned to Group B. Before entering the 2nd 30-minute walking session, all subjects were informed again that they can stop the treadmill walking at any time they request.

Gait Analysis

Gait analysis was conducted over-ground along a straight 8-meter walkway. An eight-camera motion capture system (Oxford Metrics Limited, West Way, Oxford, UK) sampling at 200Hz was synchronized with two force platforms (Advanced Mechanical Technology, Inc., Watertown, US),embedded midway on the walkway sampling at 1000 Hz. Reflective markers were affixed to the right and left heel, lateral and medial malleoli, dorsum of the foot, medial/lateral femoral condyles, greater trochanter, anterior/ posterior superior iliac spine, iliac crest, mid-thigh and med-shank (Winter, 1991). At least five successful gait trials were collected for each participant. The trials were considered successful when the whole foot fell in full contact within the force platform.

Spatial temporal, kinematic and kinetic gait data were analyzed using commercial Visual 3D™ (C-Motion, Inc. Germantown, US). Ground reaction forces in the vertical (GRFz) and anterior (GRFx) directions were analyzed, and walking speed, cadence, stance time, step length, angles, moments and powers of the ankle, knee and hip joints were calculated. The gait data were low-pass filtered with a 4th-order Butterworth filter with a 6 Hz cutoff frequency.

Local maxima and interest points in kinematic and kinetic data were determined within the gait cycle of each successful walking trial. GRF, moment, and power data were normalized to the body mass. Kinematic and kinetic data were analyzed in dominant and non-dominant limbs. The dominant leg was determined by asking the subjects the side of the leg they would use to kick the ball.(Chapman, Chapman, & Allen, 1987)

Statistical Analysis

All spatial temporal data, as well as points of interest of kinetic and kinematic data within the gait cycles were averaged across repeated trials of each subject, and averaged across subjects at each of the three test sessions.

Two-way mixed-design ANOVA was used to assess if there were significant differences in all measured parameters 1) among the three test sessions (main time effects), 2) between Group A and B (main group effects), and 3) interaction among the three test sessions and the two subject groups. If the ANOVA indicated significant differences, post-hoc Bonferroni method was used to perform multiple pair-wise comparisons among the test sessions and the subject groups. Significance level was set at 0.05. All statistical analysis was conducted using SPSS v.20.0 (SPSS Statistics. IBM Corp. Armonk, New York, US).

Results

Four subjects were dropped out. Three subjects requested to stop the treadmill walking at the 2nd treadmill walking session, and one dropped out due to the corruption of data and the inability to arrange for another gait test. A total of twenty four subjects (16 males and 8 females) completed the 60-min walk and gait tests, with a mean age of 69.7y (SD 5.1), mean height of 162.3cm (SD7.5), and mean mass of 61.8Kg (SD 10.2).

Fourteen subjects (9 males and 5 females) were allocated to Group A, with a mean age of 69.5 y (SD 5.0), height of 162.2 cm (SD 8.2), mass of 62.9 Kg (SD 9.1). Ten subjects (7 males and 3 females) were allocated to Group B with a mean age of 70 y (SD 5.0), height of 162.5 cm (SD 6.8), and mass of 60.3 Kg (SD 11.9).

Two-way ANOVA indicated significant interaction in Borg scores between the two groups and three test sessions. Post-hoc analysis (Figure 2) revealed that the mean score in the Borg scale in Group B was significantly increased from 1.5 (SD 1.0) at the baseline to 3.6 (SD 0.8) and 4.2 (SD 0.9) after 30-minute (P=0.038) and 60 minute (P <0.001) walking, respectively. The Borg scores were significantly higher in Group B than Group A after both sessions of treadmill walk. Although the Borg score in Group A was increased from 0.94 (SD 0.8) (baseline) to 1.1 (SD 0.8) and 1.4 (SD 1.1) after 30-minute and 60-minute walking, respectively, the differences were not statistically significant as indicated by Post-hoc analysis. No significant differences in age, height, mass and basal Borg score were found between Groups A and B.

. Numerical data of all analyzed gait parameters are presented in the Appendices. Post-hoc analysis revealed that Group A had significantly longer step length (P <0.001) as well as larger hip angle, and moment at heel strike (P <0.001) at both sides than Group B at the baseline. Group A was also higher in non-dominant sided knee flexor moment and power (P <0.001), and dominant hip flexor moment (P = 0.04), and power (P =0.013) at terminal stance at the baseline.

Post-hoc analysis also revealed that significant changes in a number of measured parameters across the three test sessions occurred in Group B only. Compared to the baseline, dominant sided step length and swing time of group B increased significantly after both walking sessions (P <0.001), while in the opposite side the two parameters decreased significantly (P = 0.015) (Figure 3 and Figure 4). On the contrary, stance time decreased significantly in the dominant side and increased significantly in the opposite side after both walking sessions (P <0.001).

After 60-minute walking; Group B appeared to have reduced ankle joint motion at the dominant side. They had significant reductions in the dominant-side plantar flexion angle at about 10% of the gait (P <0.001) by 31% and dorsiflexion angle at about 50% of the gait (P <0.001) by 17%. Dorsiflexor power absorption (~10% of the gait) was also significantly reduced (P >0.01) after 30-minute and 60-minute walking. Plantar flexion angle at about 60% of the gait after 60-minute walking was also significantly lower by 17% compared to the test session after 30-minute walking (P = 0.003). The dominant-side ankle plantar flexion moment and the concentric plantar flexor power generation (~ 50% of the gait) decreased significantly after 60-min walking by 10% (P =0.043) and 18 % (P =0.033), respectively.

On the contrary, significant increases in joint motions were found in the non-dominant side in Group B. After 60-minute walking the non-dominant side knee flexion angle and extensor power generation (~20% of the gait cycle) were significantly higher by 25% (p<0.001) and 44 %(P =0.011), respectively, compared to the baseline. Non-dominant sided hip extension angle at about 50% of the gait increased significantly after the 30-minute (6%, P =0.001), and the 60-minute walking (15%, P =0.028). During the same period of gait cycle, non-dominant hip flexor moment increased significantly by 10% after 30-min walking (*P* =0.035), and by 15% after 60-min walking (*P* =0.019). The hip flexor power absorption was significantly increased by 22% after 60-minute walking (*P* >0.01) and 15% comparing the two walking sessions (*P* =0.015).

Discussion

To the best knowledge of the authors, this is the first study investigating long-distance walking of the older adults. Subjects in Group B would normally take a rest after 30 minutes of walking. Subject grouping was based on subjective response. However, the degree of perceived exertion was measured by Borg CR10 scale, which indicated significant difference between the two groups. Borg scale is widely used as a valid measure to assess fatigue and tiredness after physical activity in older adults (Egerton, Brauer, & Cresswell, 2009), and it is considered the most sensitive scale for general fatigue compared to other subjective scales. (Grant et al., 1999) Group B scored an average of 3.6 at the Borg CR10 scale (moderate to somewhat strong level of exertion), significantly higher than Group A which scored an average of 1.1 (very light level of exertion) after 30 minutes of continuous walk. There were many parameters which changed differently between the two groups across the three test sessions. While lack of motivation was suggested to be one major reason for insufficient walking among healthy older adults, the gait characteristics of Group B as compared to Group A implied that some biomechanical factors could also play an important role.

At the baseline, Group B had significantly smaller hip flexion angle at heel strike and significantly shorter step length than Group A. Meanwhile, the cadence of Group B was noticeably 8.5% higher than Group A. Smaller hip flexion angle at the end of swing phase can lead to shorter step length. The higher cadence of Group B might be a mean of compensating for the shorter step length such that the walking speed would not be too slow. The higher cadence (steps per minute) of Group B meant that they walked more steps in a given time. This could cause lower-limb muscles to develop fatigue more easily, potentially posing some difficulty to walk long distances.

The step length, stance and swing time at the dominant and the non-dominant legs of Group B changed significantly in opposite directions, widening the differences between both legs, after the long-distance walk. Such finding was not observed in Group A. It should be noted that previous studies suggested asymmetry in these gait parameters was positively correlated to risk of fall and dependency in daily living activity among older adults (Bautmans, Jansen, Van

Keymolen, & Mets, 2011), (Yogev, Plotnik, Peretz, Giladi, & Hausdorff, 2007). In addition, fear of fall was considered to be one reason for sedentary lifestyle of the older adults (Moschny, et al., 2011).

After the long-distance walk, Group B had significant reductions in the dominant-side dorsiflexor power absorption at early stance and plantar flexor power generation during terminal stance. Such reductions could be signs of fatigue of both muscle groups in the dominant side. This agrees with a previous study on young subjects which revealed that those who got tired easily after the three hours of free walking showed local fatigue of muscles acting at the ankle (Yoshino, Motoshige, Araki, & Matsuoka, 2004). Previous studies on young adults have also revealed that following muscle fatigue, subjects avoided shock absorption by reducing eccentric contraction and propulsion (Voloshin, Mizrahi, Verbitsky, & Isakov, 1998) by reducing joint power generation.

The fatigue of dominant-side plantar flexors of Group B could be linked to their significant reductions in dominant-side dorsiflexion angle immediately after mid-stance and plantar flexion at terminal stance. Smaller dorsiflexion angle after mid-stance lowered the plantar flexor moment and the required counteracting force from the plantar flexor (Mueller, Minor, Schaaf, Strube, &

Sahrmann, 1995). Meanwhile, reduced plantar flexion at terminal stance reduced propulsion, which could also provide relief to fatigued plantar flexor to some extent. Reduced propulsion at the dominant side after long-distance walk was further evidenced by the significant reductions in peak propulsive force and the 2nd peak vertical GRF. On the other hand, the fatigue of the dominant-side dorsiflexors of Group B could be linked to their significantly reduced braking force, the 1st peak vertical GRF as well as plantar flexion angle immediately after heel strike. Dorsiflexors control the lowering of the foot immediately after heel strike. The lowered magnitude of force acting on the heel together with the small plantar flexion angle at early stance reduced the required eccentric contraction of dorsiflexors.

Group B showed significant increase in non-dominant side knee flexion angle during early stance and hip extension angle during terminal stance after long-distance walk. These could be the strategies to compensate for the fatigued plantar flexors and dorsiflexors at the dominant side. The fatigued plantar flexors at the dominant side reduced the forward push-off at terminal stance. Shortly after the dominant leg approached to terminal stance, body weight was transferred to the non-dominant leg (Perry & Burnfield). Knee flexion during early stance brought about the anterior rotation of the tibia, which provided forward body movement (Perry & Burnfield). The significant increase in the non-dominant side knee flexion angle during early stance could compensate for the reduced push off of the dominant side. On the other hand, the significantly increased non-dominant side hip extension angle during terminal stance together with the significant extension of its stance phase might prepare the dominant leg to land more softly on the floor. This could be the cause of reduced peak braking force and the 1st peak vertical GRF of the dominant side, reducing the loading of the dorsiflexors.

This study has identified several factors which could be related to the ability of long-distance walking of the adults aged 65 or more. At the baseline, Group B had higher cadence than Group A which may increase the likelihood of developing muscle fatigue at the lower limbs. The higher cadence could be caused by the smaller hip flexion angle during late swing phase and shorter step length. Future studies can identify if increasing hip flexion during late swing phase can facilitate long distance walking. Physical training which targets to increase the endurance and strength of hip flexors and gait training reminding older adults to flex the hip joint more during late swing phase could be possible approaches. In addition, fatigue of dominant-side plantar flexors and dorsiflexors developed in Group B after the long-distance walk could have induced some compensatory movements of the non-dominant side. Future attempts can increase the endurance of plantar flexors and dorsiflexors especially at the dominant side and evaluate if this reduces the compensatory movements upon long-distance walking. Some spatial-temporal parameters of two legs changed significantly in opposite directions after the long-distance walk, sparking concern if this implied higher risk of fall in some healthy older adults who are less able to walk long distances. Gait analysis is usually used to compare the effects of various physical training protocols on walking patterns. Such analysis should not overlook the effect of long-distance walking, as different physical characteristics of older adults could develop different walking patterns upon walking long distances.

Conclusion

Subjects in Group B normally take a rest after walking for 30 minutes or less. They had noticeably lower basal hip flexion at heel strike and step length of both sides than their counterparts who perceived significantly less physical exertion after the walk. Upon long-distance walking, step length, swing and stance time of Group B changed significantly in opposite directions for both legs. This warrants further investigation in association with fall. They also exhibited a compensatory gait pattern in which the non-dominant side knee and hip joints produced larger motion, which appeared to compensate for the reduced dominant-side ankle motions. Such analysis could inspire pragmatic ways of facilitating long-distance walking of the older adults.

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Captions

Figure 1:

Borg CR10 Scale for perceived exertion.

Figure 2:

Scores in Borg CR10 Scale of Group A and B over different time points

Figure 3:

Group B joint angles, moments and powers of the ankle, knee, and hip joints and the GRFs averaged among the subjects in a complete gait cycle for the dominant side.

Figure 4:

Group B joint angles, moments and powers of the ankle, knee, and hip joints and the GRFs averaged among the subjects in a complete gait cycle for the non-dominant side.

✔	**Marks**	**Exertion Scale**
	0	Nothing at all
	0.5	Extremely light
	1	Very light
	2	Light
	3	Moderate
	4	Somewhat strong
	5	Strong
	6	
	7	Very strong
	8	
	9	
	10	Extremely strong

Figure 1: Borg CR10 Scale for perceived exertion.

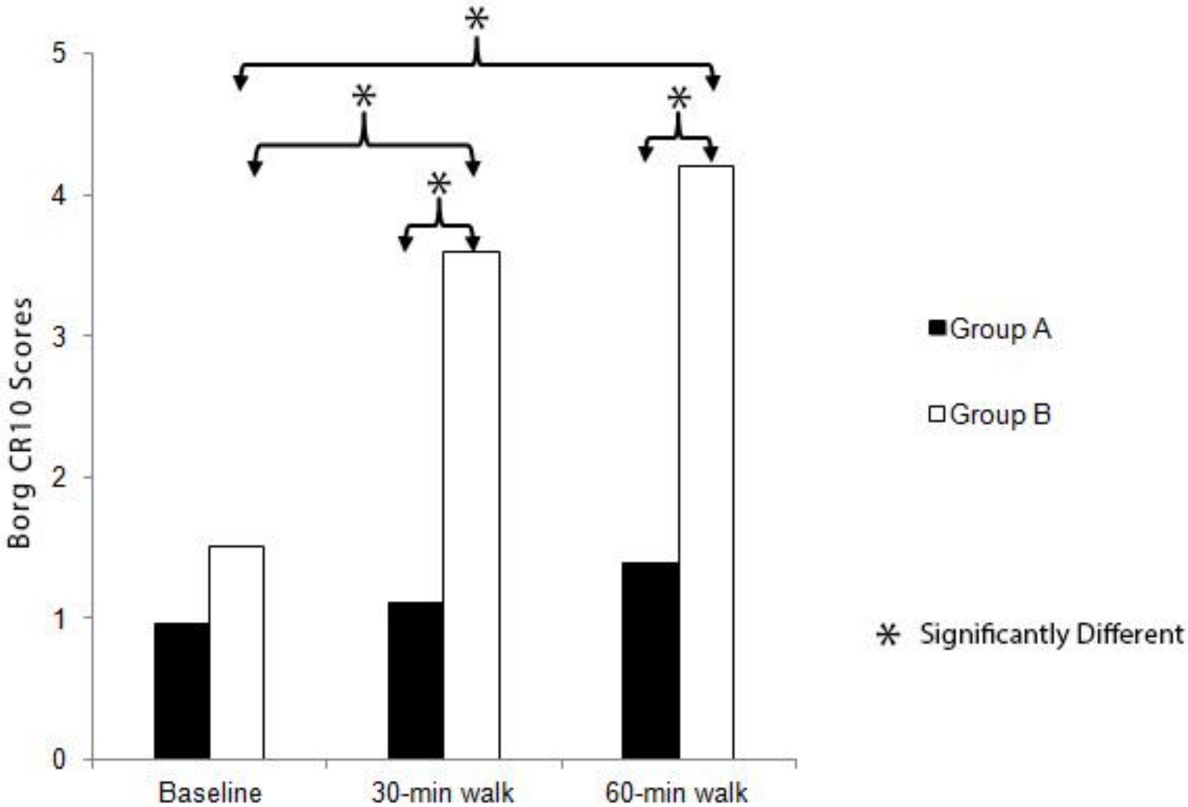

Figure 2: Scores in Borg CR10 Scale of Group A and B over different time points

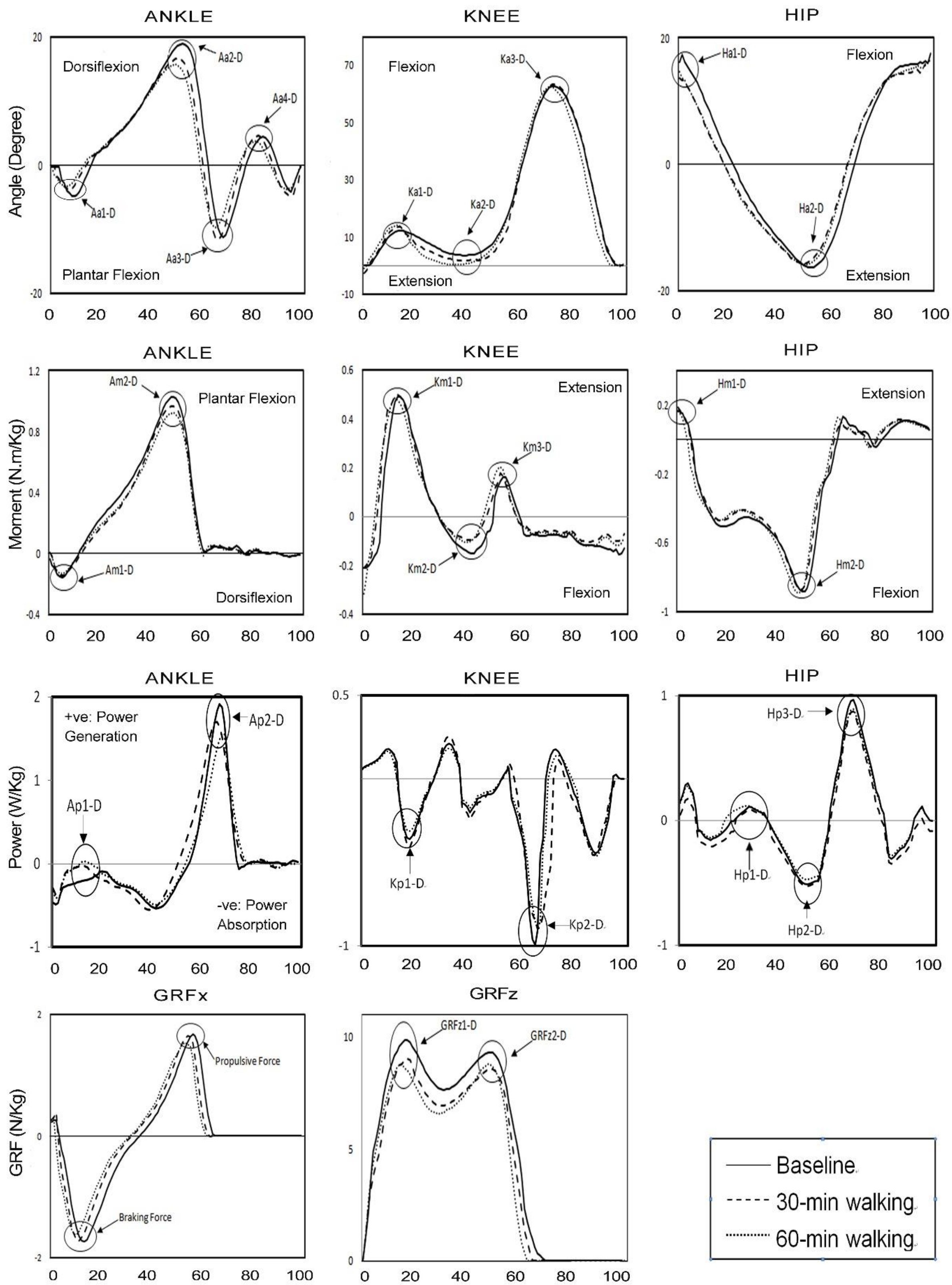

Figure 3: Group B joint angles, moments and powers of the ankle, knee, and hip joints and the GRFs averaged among the subjects in a complete gait cycle for the dominant side.

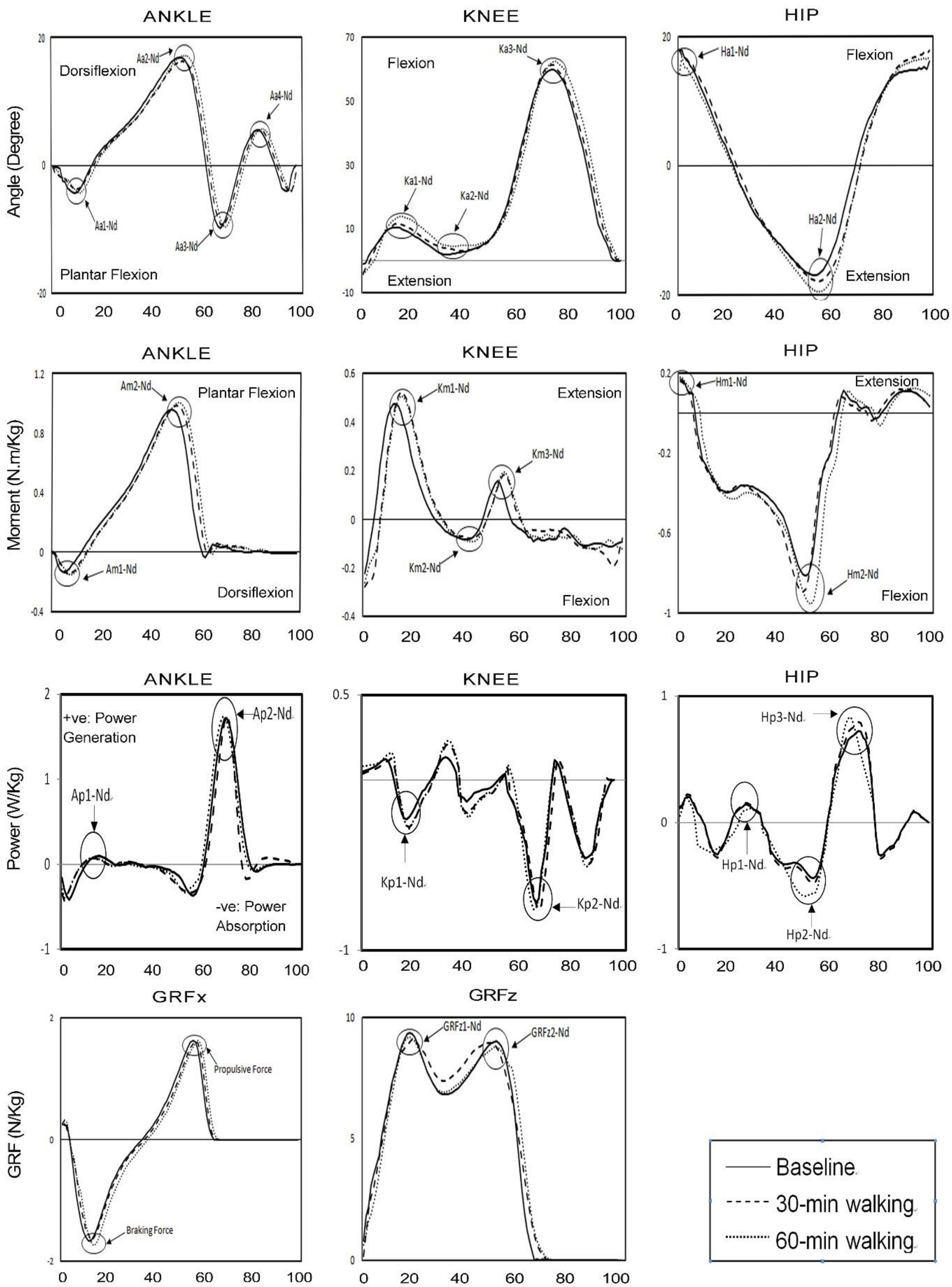

Figure 4: Group B joint angles, moments and powers of the ankle, knee, and hip joints and the GRFs averaged among the subjects in a complete gait cycle for the non-dominant side.

Appendix 1. Mean (SD) of Group A gait parameters' points of interest at three time points.

Gait parameters	***Baseline***	***30-min***	***60-min***
Walking speed (m/s)	1.15(0.16)	1.14(0.18)	1.20(0.18)
Cadence (Steps/min)	106(11.1)	105(13.8)	106(11.2)
Step length (m)			
*Dominant	0.63(0.07)	0.64(0.08)	0.65(0.08)
*Non-Dominant	0.66(0.05)	0.66(0.09)	0.65(0.06)
Stance time (sec)			
Dominant	0.63(0.05)	0.61(0.03)	0.60(0.03)
Non-Dominant	0.63(0.05)	0.61(0.02)	0.61(0.02)
Swing time (sec)			
Dominant	0.46(0.03)	0.45(0.04)	0.45(0.04)
Non-Dominant	0.46(0.04)	0.45(0.04)	0.43(0.04)
GRF(N/Kg)			
Peak braking force			
Dominant	1.63 (0.26)	1.79(0.32)	1.69(0.42)
Non-Dominant	1.69(0.31)	1.59(0.30)	1.64(0.39)
Peak propulsive force			
Dominant	1.65(0.34)	1.65(0.27)	1.59(0.34)
Non-Dominant	1.58(0.30)	1.53(0.34)	1.55(0.38)
Peak vertical GRF 1			
Dominant	9.47(1.61)	9.64(1.39)	9.89(1.32)
Non-Dominant	9.03(1.46)	9.65(1.34)[a]	9.38(1.44)
Peak vertical GRF 2			
Dominant	9.18(1.34)	9.34(1.30)	9.48(1.31)
Non-Dominant	8.88(1.40)	9.24(1.28)[a]	9.08(1.21)
Joint angle (degree)			
Ankle (~10% gait)			
Dominant (Aa1-D)	-5.18(1.2)	-4.81(0.6)	-4.74(0.9)
Non-Dominant (Aa1-Nd)	-4.49(1.3)	-4.89(1.2)	-4.67(1.0)
Ankle (~50% gait)			
Dominant (Aa2-D)	18.34(3.2)	19.08(2.4)	18.97(2.1)
Non-Dominant (Aa2-Nd)	17.18(2.8)	17.94(4.3)	17.17(2.7)
Ankle (~60% gait)			
Dominant (Aa3-D)	-10.36(4.3)	-10.06(4.7)	-10.11(3.2)
Non-Dominant (Aa3-Nd)	-10.55(3.7)	-10.84(3.4)	-10.69(4.0)
Ankle (~80% gait)			
Dominant (Aa4-D)	6.21(2.6)	5.82(1.4)	5.60(2.4)
Non-Dominant (Aa4-Nd)	4.83(1.4)	5.27(2.5)	4.77(1.7)
Knee (~20% gait)			
Dominant (Ka1-D)	10.16(4.5)	11.32(3.6)	11.12(7.4)
Non-Dominant (Ka1-Nd)	10.38(3.4)	11.20(3.1)	14.02(3.5)[a] ^
Knee (~40% gait)			
Dominant (Ka2-D)	3.64(5.2)	4.05(4.3)	4.58(2.7)
Non-Dominant (Ka2-Nd)	2.78(3.8)	4.08(3.2)	4.68(3.4)
Knee (~70% gait)			
Dominant (Ka3-D)	61.05(4.7)	59.07(5.2)	62.28(8.1)
Non-Dominant (Ka3-Nd)	57.98(7.4)	57.97(6.4)	61.16(7.8)[a] ^
Hip (~1% gait)			
*Dominant (Ha1-D)	25.43(9.3)	25.64(6.7)	25.14(8.4)
*Non-Dominant (Ha1-Nd)	22.20(7.4)	25.59(6.5)	24.82(7.6)
Hip (~50% gait)			
Dominant (Ha2-D)	-17.99(5.7)	-18.41(5.3)	-18.14(7.6)
Non-Dominant (Ha2-Nd)	-15.71(7.2)	-15.75(7.9)	-15.34(8.1)

(Continued)

Gait parameters	***Baseline***	***30-min***	***60-min***
Joint moment (Nm/Kg)			
Ankle (~10% gait)			
Dominant (Am1-D)	-0.18(0.09)	-0.19(0.07)	-0.19(0.09)
Non-Dominant (Am1-Nd)	-0.19(0.01)	-0.17(0.09)	-0.18(0.06)
Ankle (~50% gait)			
Dominant (Am2-D)	1.02(0.17)	1.03(0.17)	1.05(0.19)
Non-Dominant (Am2-Nd)	0.97(0.14)	1.00(0.19)	1.06(0.18)
Knee (~15% gait)			
Dominant (Km1-D)	0.49(0.29)	0.54(0.22)	0.55(0.37)
Non-Dominant (Km1-Nd)	0.51(0.23)	0.47(0.20)	0.55(0.23)^
Knee (~40% gait)			
Dominant (Km2-D)	-0.13(0.09)	-0.14(0.29)	-0.09(0.19)
*Non-Dominant (Km2-Nd)	-0.13(0.12)	-0.14(0.24)	-0.12(0.13)
Knee (~60% gait)			
Dominant (Km3-D)	0.18 (0.19)	0.21(0.16)	0.20(0.11)
Non-Dominant (Km3-Nd)	0.16(0.21)	0.16(0.19)	0.18(0.17)
Hip (~1% gait)			
*Dominant (Hm1-D)	0.41(0.28)	0.43(0.22)	0.45(0.23)
*Non-Dominant (Hm1-Nd)	0.40(0.31)	0.39(0.24)	0.41(0.19)
Hip (~50% gait)			
*Dominant (Hm2-D)	-0.93(0.19)	-0.88(0.35)	-1.04(0.25)[a] ^
Non-Dominant (Hm2-Nd)	-0.79(0.14)	-0.83(0.42)	-0.84(0.22)
Joint Power (W/Kg)			
Ankle (~10% gait)			
Dominant (Ap1-D)	-0.89(0.06)	-0.77(0.04)	-0.75(0.03)
Non-Dominant (Ap1-Nd)	-0.68(0.04)	-0.68(0.05)	-0.71(0.08)
Ankle (~60%gait)			
Dominant (Ap2-D)	2.05(0.2)	2.13(0.8)	2.17(0.1)
Non-Dominant (Ap2-Nd)	1.98(0.5)	1.98(0.4)	2.12(0.4)
Knee (~20% gait)			
Dominant (Kp1-D)	0.27(0.06)	0.22(0.03)	0.20(0.07)
Non-Dominant (Kp1-Nd)	0.20(0.08)	0.18(0.05)	0.29(0.07)^
Knee(~50% gait)			
Dominant (Kp2-D)	-1.35(0.3)	-1.32(0.8)	-1.24(0.3)
*Non-Dominant (Kp2-Nd)	-1.24(0.6)	-1.15(0.7)	-1.19(0.1)
Hip (~20% gait)			
*Dominant (Hp1-D)	0.39(0.1)	0.31(0.1)	0.29(0.1)
*Non-Dominant (Hp1-Nd)	0.35(0.2)	0.34(0.08)	0.34(0.06)
Hip (~50% gait)			
Dominant (Hp2-D)	-0.49(0.01)	-0.48(0.08)	-0.58(0.04)[a] ^
Non-Dominant (Hp2-Nd)	-0.64(0.09)	-0.66(0.02)	-0.65(0.05)
Hip (~70% gait)			
Dominant (Hp3-D)	0.93(0.2)	0.84(0.1)	0.94(0.3)
Non-Dominant (Hp3-Nd)	0.85(0.4)	0.73(0.09)	0.79(0.2)

Note: Refer to Figure 2 and Figure 3 for locations of the points of interests in a gait cycle

* Baseline measurement significantly different compared to Group B ($p < 0.05$)

[a] Significantly different when compared to baseline ($p < 0.05$).

^ Significantly different when compared to 30-min walk ($p < 0.05$).

Appendix 2. Mean (SD) of Group B gait parameters' points of interest at three time points

Gait parameters	*Baseline*	*30-min*	*60-min*
Walking speed (m/s)	1.09(0.10)	1.11(0.13)	1.10(0.11)
Cadence (Steps/min)	115.1(9.5)	115.4(8.9)	112.9(7.1)
Step length (m)			
*Dominant	0.59(0.05)	0.61(0.03)[a]	0.64(0.05)^[a]
*Non-Dominant	0.62(0.04)	0.59(0.04)	0.55(0.03)[a]
Stance time (sec)			
Dominant	0.62(0.02)	0.57(0.02)[a]	0.52(0.01)^[a]
Non-Dominant	0.62(0.01)	0.67(0.02)[a]	0.75(0.03)^[a]
Swing time (sec)			
Dominant	0.42(0.01)	0.43(0.03)[a]	0.48(0.03)^[a]
Non-Dominant	0.43(0.03)	0.40(0.02)[a]	0.36(0.02)^[a]
GRF(N/Kg)			
Peak braking force			
Dominant	1.73(0.46)	1.71(0.44)	1.61(0.49)[a]
Non-Dominant	1.66(0.39)	1.64(0.39)	1.73(0.41)[a]
Peak propulsive force			
Dominant	1.67(0.57)	1.65(0.51)	1.53(0.48)[a]
Non-Dominant	1.63(0.49)	1.61(0.44)	1.62(0.43)
Peak vertical GRF 1			
Dominant	9.85(2.5)	9.03(1.87)[a]	8.79(1.94)[a]
Non-Dominant	9.33(2.7)	9.10(1.89)	9.17(1.94)
Peak vertical GRF 2			
Dominant	9.31(1.66)	8.58(1.87)	8.77(1.84)[a]
Non-Dominant	8.99(1.74)	8.95(1.89)	8.78(1.82)
Joint angle (degree)			
Ankle (~10% gait)			
Dominant (Aa1-D)	-4.88(1.7)	-3.76(1.5)[a]	-3.35(1.7)^[a]
Non-Dominant (Aa1-Nd)	-4.32(1.4)	-3.74(1.8)	-4.32(2.1)
Ankle (~50% gait)			
Dominant (Aa2-D)	18.98(3.2)	16.70(3.2)[a]	15.73(3.8)^[a]
Non-Dominant (Aa2-Nd)	16.88(2.5)	16.27(1.4)	17.20(2.4)
Ankle (~60% gait)			
Dominant (Aa3-D)	-11.18(5.4)	-11.57(4.8)	-9.68(6.2)^
Non-Dominant (Aa3-Nd)	-9.76(4.8)	-9.41(4.2)	-9.66(5.8)
Ankle (~80% gait)			
Dominant (Aa4-D)	4.44(2.7)	4.59(2.4)	3.80(2.4)
Non-Dominant (Aa4-Nd)	5.53(1.3)	5.54(1.2)	5.74(2.3)
Knee (~20% gait)			
Dominant (Ka1-D)	12.24(7.4)	13.58(5.0)	14.09(6.2)
Non-Dominant (Ka1-Nd)	10.48(4.4)	11.56(3.7)	13.79(4.2)^[a]
Knee (~40% gait)			
Dominant (Ka2-D)	3.52(4.3)	1.73(3.6)	0.24(4.8)[a]
Non-Dominant (Ka2-Nd)	1.98(2.7)	3.23(2.7)	4.61(3.4)
Knee (~70% gait)			
Dominant (Ka3-D)	62.80(7.3)	63.41(6.8)	62.55(8.9)
Non-Dominant (Ka3-Nd)	59.92(6.5)	61.44(8.3)	62.43(8.5)
Hip (~1% gait)			
*Dominant (Ha1-D)	16.20(4.2)	14.71(5.3)	14.61(6.4)
*Non-Dominant (Ha1-Nd)	17.79(5.1)	17.97(4.8)	14.23(5.3)
Hip (~50% gait)			
Dominant (Ha2-D)	-16.26(7.9)	-15.66(8.5)	-15.82(7.6)
Non-Dominant (Ha2-Nd)	-16.96(6.6)	-18.04(6.8)[a]	-19.58(6.2)[a]

(Continued)

Gait parameters	***Baseline***	***30-min***	***60-min***
Joint moment (Nm/Kg)			
Ankle (~10% gait)			
Dominant (Am1-D)	-0.15(0.07)	-0.14(0.04)	-0.13(0.04)
Non-Dominant (Am1-Nd)	-0.14(0.08)	-0.15(0.05)	-0.15(0.07)
Ankle (~50% gait)			
Dominant (Am2-D)	1.02(0.13)	0.96(0.17)	0.92(0.20)[a]
Non-Dominant (Am2-Nd)	0.95(0.18)	0.98(0.20)	1.01(0.18)
Knee (~15% gait)			
Dominant (Km1-D)	0.49(0.32)	0.49(0.28)	0.48(0.29)
Non-Dominant (Km1-Nd)	0.47(0.28)	0.52(0.25)	0.51(0.21)
Knee (~40% gait)			
Dominant (Km2-D)	-0.15(0.13)	-0.09(0.17)	-0.10(0.18)
*Non-Dominant (Km2-Nd)	-0.08(0.07)	-0.07(0.18)	-0.09(0.12)
Knee (~60% gait)			
Dominant (Km3-D)	0.16(0.19)	0.17(0.11)	0.21(0.18)
Non-Dominant (Km3-Nd)	0.15(0.16)	0.18(0.09)	0.19(0.19)
Hip (~1% gait)			
*Dominant (Hm1-D)	0.16(0.28)	0.18(0.19)	0.17(0.21)
*Non-Dominant (Hm1-Nd)	0.17(0.24)	0.18(0.22)	0.18(0.19)
Hip (~50% gait)			
*Dominant (Hm2-D)	-0.88(0.15)	-0.87(0.15)	-0.89(0.14)
Non-Dominant (Hm2-Nd)	-0.81(0.14)	-0.89(0.17)[a]	-0.95(0.16)^[a]
Joint Power (W/Kg)			
Ankle (~10% gait)			
Dominant (Ap1-D)	-0.89(0.06)	-0.77(0.04)	-0.75(0.03)
Non-Dominant (Ap1-Nd)	-0.68(0.04)	-0.68(0.05)	-0.71(0.08)
Ankle (~60%gait)			
Dominant (Ap2-D)	-0.20(0.13)	-0.03(0.07)	0.02(0.09)[a]
Non-Dominant (Ap2-Nd)	0.09(0.06)	0.07(0.05)	0.07(0.07)
Knee (~20% gait)			
Dominant (Kp1-D)	1.92(0.5)	1.70(0.5)	1.56(0.5)[a]
Non-Dominant (Kp1-Nd)	1.72(0.7)	1.74(0.4)	1.74(0.8)
Knee(~50% gait)			
Dominant (Kp2-D)	0.21(0.03)	0.25(0.06)	0.18(0.04)
*Non-Dominant (Kp2-Nd)	0.13(0.08)	0.21(0.02)	0.23(0.03)[a]
Hip (~20% gait)			
*Dominant (Hp1-D)	-0.99(0.6)	-0.89(0.8)	-1.24(0.3)
*Non-Dominant (Hp1-Nd)	-0.72(0.2)	-0.76(0.2)	-0.88(0.7)
Hip (~50% gait)			
Dominant (Hp2-D)	0.11(0.06)	0.08(0.4)	0.11(0.3)
Non-Dominant (Hp2-Nd)	0.14(0.3)	0.16(0.05)	0.11(0.05)
Hip (~70% gait)			
Dominant (Hp3-D)	-0.51(0.09)	-0.52(0.07)	-0.47(0.09)
Non-Dominant (Hp3-Nd)	-0.44(0.1)	-0.48(0.2)	-0.56(0.15)^[a]

Note: Refer to Figure 2 and Figure 3 for locations of the points of interests in a gait cycle

* Baseline measurement significantly different compared to Group A ($p < 0.05$)

[a] Significantly different when compared to baseline ($p < 0.05$).

^ Significantly different when compared to 30-min walk ($p < 0.05$).