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Biomechanical Approach in Facilitating Long-Distance Walking of Elderly People Using Footwear Modifications

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ABSTRACT

This study assessed if silicon insoles with heel lifts (named here the prescribed insoles) could facilitate long-distance walking of older adults. Fifteen adults aged over 65, who did not have obvious lower-limb problems, walked on a treadmill for totally 60 minutes in two separate walking sessions: 1) with the prescribed insoles, and 2) with original insoles of the standardized shoes. Gait tests using force plates and a motion analysis system, and subjective evaluation using visual analoge and Borg's CR10 scales were conducted at different time points of the treadmill walking. Objective gait anaylsis showed that without using the prescribed insoles, there were significant reductions ($p<0.05$) in stance time, vertical ground reaction force, ankle dorsiflexion angle and ankle power generation of the dominant leg after the 60-minute treadmill walk. Such significant reductions were not observed in the same group of subjects upon using the prescribed insoles. Meanwhile, significant improvements in subjective perception of physical exertion, pain and fatigue were observed. Heel lifts and silicon insoles are generally used to relieve plantar pain and reduce strain of plantar flexors in patients. This study showed they might also be solutions to facilitate long-distance walking of older adults, an approach which could prompt their physical activity.

Key Terms: Insoles; Gait; Older adults; Long-Distance Walking; Physical Activity; Fatigue

Word count: 2997.

Highlights

Regular physical activity provides tremendous health benefits.

However, age degeneration and fatigue could restrict elderly people from walking long distances.

This study showed heel lifts and silicon insoles could facilitate long-distance walking of elderly people who did not have obvious lower-limb problems.

This potentially offers a solution to geriatricians and healthcare workers to prompt physical activity of elderly people.

Introduction

Improving health and preventing disease in the elderly population are among the top priorities in health-care policy of many governments. Evidence suggests that regular physical activity can reduce fall-related injuries [1], cognitive declination [2] and mortality rates [3] among older adults. Long-distance walking is a safe and convenient way of exercise for older people [4], which can easily be integrated into their daily routine [1]. Walking for over an hour per day was found to be able to reduce the risk of mortality [3] and disability [5] of the elders. However, walking ability clearly declines with advancing age [6]. A meta-analysis of 42 studies indicated that adults aged over 65 walked only an average of about 3,000 steps per day [7], less than a total 30 minutes of walking per day.

Muscle weakening and fatigue could be the major reasons for the difficulty faced by the healthy elders walking long distances. Over the age of 60, muscle strength decreases by an average of 3% per year [8]. In addition, older people have even greater relative force loss than young adults and slower return to resting levels, after the muscles become fatigued [9]. Plantarflexors were found to be more susceptible to fatigue than other lower-limb muscles [10]. Fatigued plantarflexors could lower the abilities of shock absorption and motion generation [10], which potentially affect the ability of long-distance walking.

Discomfort and pain at the plantar surface of the foot could also account for the lack of walking among elderly people. The pain may not occur at the beginning of the day, but it may be perceived after some walking [11]. This could be explained by the hysteresis of the soft tissue at the plantar foot reducing its stiffness upon repeated loading [12]. A previous study suggested that after a long-distance walk the gait of the young adults changed to reduce loading at the forefoot which could be a response of avoiding pain and discomfort [13]. There is a lack of studies investigating the changes in level of pain at the lower-limb upon long-distance walking of older people. However, it was documented that older people have lower shock absorption ability of the soft tissue at the plantar foot [14], potentially bringing them more susceptible to foot pain upon repeated loading at the feet.

Modifying the forces applied to the lower limbs might address the biomechanical problems. Traditionally, orthopedic insoles are used to treat patients with foot pain. Silicone insoles were found effective in relieving foot pain in patients [15], inducing a significant reduction in peak plantar pressure [16] and soft tissue strain [17]. In addition, a wedge lifting the heel has been used to reduce the stretching of plantarflexors during lomoction, reducing further strain and fatigue [18]. Advantages of heel lifting in amputee population included a reduction in power generation of plantarflexors and a facilitation to walk longer distances [19]. Footwear modification has been used with success to treat a variety of foot problems [15-18]. However, little attempt has been made to use such approach to facilitate long-distance walking of older people.

This study examined whether modification of shoe inserts, with the use of a full-length silicone insole and a heel lift, could facilitate long distance walk of the elderly. Gait tests measuring spatial–temporal, kinetic and kinematic parameters as well as evaluation of perceived level of physical exertion, fatigue and pain were conducted in the same group of older adults who walk for one hour with and without the shoe inserts modifications. It was hypothesized that such footwear modifications reduced pain and fatigue, producing noticeable improvements in perceived exertion and gait patterns of older people walking long distances.

Methods

Subjects

A convenience sample of 15 elderly subjects (age > 65 years) participated in this study. Subjects should be aged over 65, living in a community-based setting, and capable of ambulation without any walking aids. They should not have a history of fall in the past year, cardiovascular or pulmonary diseases, diabetes, cancer, uncontrolled hypertension. They should not have any lower-limb pain or deformities that affect walking, as assessed by a certified orthoptist following standard procedures specified in [20]. Their passive ankle range of motion was not smaller than the reported average values among older people presented in a previous study (dorsiflexion 8 degrees and plantarflexion 35 degrees) [21]. This study was approved by the university's Human Subject Ethic Sub-committee, with all methods performed in accordance with its relevant guidelines and regulations. This study was registered in the Chinese Clinical Trial Registry (clinical trial registration numbers: ChiCTR-IPB-15006530).

Design of the prescribed insoles

The prescribed insoles were incorporated with two features 1) a 3-mm thick full-length silicone gel insoles (Jing Jian Da, Beijing, China) and 2) a 20-mm Ethylene Vinyl Acetate (EVA) (40 Shore A hardness) heel lift. The silicone gel insoles were trimmed to fit the subjects' shoes size. The full-length insole and the heel lift were adhered together and inserted in the shoes after removing the original insole.

Experimental Design

Each subject participated in two walking sessions, which were conducted on separate days (4-7 days apart depending on the availability of the subjects). The subjects wore the prescribed insoles on both feet in one walking session. In another walking session, they wore the original insoles provided by the shoes. In both walking sessions, standardized running shoes (NIKE Air Pegasus, Beaverton, OR, USA) were used. Each subject was fitted the shoes without looking at the insoles by the experimenters. The order of the two sessions for each subject was randomized by computer-generated random numbers of one and two denoting the two possible orders.

In each walking session, subjects were asked to walk on a treadmill without holding the handrails for two consecutive walking trials of 30 minutes. The duration between the two walking trials was controlled as less than 3 minutes. Subjects were allowed to change the speed of the treadmill in order to walk comfortably. They could stop the treadmill walking at any time they requested. Gait tests and assessment of subjective perception were conducted three times in each walking session: 1) before the treadmill walking (baseline), 2) after the 1st 30 minutes and 3) after the 2nd 30 minutes of treadmill walking trails. Subjects walked in self-selected comfortable speed in both treadmill walking and gait analysis, to eliminate the artificial alteration of gait patterns [22].

Evaluation of perceived level of exertion, fatigue and pain

Subjects were asked to rate their level of lower-limb fatigue and pain by putting a mark on a 100mm line in the Visual Analogue Scale (VAS) (Figure 1), which had a long history of use in medical outcome studies investigating pain and fatigue [20]. The 100mm line in the scale had two ends, denoting extremes of possible answers. The lower-limb fatigue and pain scores were calculated based on the distance of the marking from the right end.

In addition, they were asked to rate the degree of physical exertion by providing a score (allowing decimals in any numbers) based on a Borg CR10 scale (Table1). Borg scale is widely used as a valid measure to assess perceived intensity of physical activity, and is considered to be the most sensitive scale for general fatigue compared to other subjective scales [23].

Gait tests

Gait tests were conducted over-ground along a straight 8-meter walkway. Motion capturing was conducted using an eight-camera system (Oxford Metrics Limited, West

Way, Oxford, UK) sampling at 200Hz and synchronized with two force platforms (Advanced Mechanical Technology, Inc., Watertown, US) sampling at 1000 Hz, which were placed midway on a straight 8-m walkway. Reflective markers were placed on the subjects' left and right lower limbs over the anterior/ posterior superior iliac spine, iliac crest, mid-thigh, med-shank, greater trochanter, medial/lateral femoral condyles, lateral and medial malleoli, heel and dorsum of the foot [24]. Each trial was considered to be successful only if the whole foot fell in full contact within the force platform. At least five successful gait trials were collected for each participant.

Spatial temporal, kinetic and kinematic gait data were analyzed using Plug-in gait in Vicon. Ground reaction forces in the anterior (GRFx) and vertical (GRFz) 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.

GRF, moment, and power data were normalized to the body mass. Within the gait cycle of each successful walking trial, local maxima and interest points in kinetic and kinematic data were determined (Figure 3 and 4). 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 [24].

Statistical analysis

The physical exertion, lower-limb pain, fatigue scores together with spatial temporal parameters and the points of interest of kinetic and kinematic data within the gait cycles were statistically analyzed. Gait data were averaged across repeated walking trials of each subject and across all participated subjects at each of the two insole conditions and three time points of the treadmill walk.

A three by two (time points x insole conditions) analysis of variance (ANOVA) with repeated measures was used to assess if there were significant differences in all measured parameters 1) among the three time points (Baseline, after 30min and 60min walk), 2) between the two insoles conditions (with and without the prescribed insoles), and 3) interaction among the three points and the two insole conditions. If the ANOVA indicated significant differences, Bonferroni-adjusted post hoc tests were conducted to perform multiple pair-wise comparisons among the time points and insole conditions. Data were analyzed using the computer program SPSS Version 20.0 (SPSS Inc., Chicago, IL). Significance level was set at 0.05.

Results

All fifteen healthy elderly subjects (11 males and 4 females, aged 71.6±6.1 years, height 162.8±7.4 cm, and weight 63.3±6.0 Kg) completed two walking sessions of: 1) wearing the original insoles of the standardized shoes, and 2) wearing the prescribed insoles and the standardized shoes on both feet.

No significant differences were found in scores on Borg's (assessing perceived level of physical exertion) and Visual Analogue Scale scales (assessing perceived level of pain and fatigue) at the baseline between the two sessions. The subjects then gave significantly ($p<0.001$) lower scores on Borg's scale (lower level of exertion) in the session with the prescribed insoles than without the insoles after 30 minutes and 60 minutes of treadmill walk (Figure 2). Without the prescribed insoles, the lower-limb pain scores were significantly increased (more pain) from 0.51 (SD 0.57) at the baseline to 2.98 (SD 0.61) and 3.11 (SD 0.54) after 30 and 60-min walking (p<0.001), respectively, Meanwhile, the lower-limb fatigue score was significantly (p=0.004) increased (more fatigue) from 0.68 (SD 0.86) to 2.19 (SD 0.22) after 60-min walk without the prescribed insoles. Such significant increases were not observed when the same group of subjects used the prescribed insoles.

Changes in spatial-temporal, kinetic and kinematic gait parameters are shown in Figure 3 and Appendix. No significant differences were found between the two sessions (with and without the prescribed insoles) at the baseline, except for the basal plantarflexion angle at about 10% of the gait cycle (first peak in the angle-time curve) which was 27% smaller (p<0.01) at the session of using the prescribed insoles. When comparing across the three time points of treadmill walk, the subjects in the two insole conditions exhibited different patterns of changes in gait patterns as detailed below:

Spatial-temporal parameters

In the session without using the prescribed insoles, the dominant-side stance time and the non-dominant side swing time was significantly reduced by about 10% (p<0.01) after 60 minutes of treadmill walk (Supplementary Table S1). No significant changes in spatial-temporal parameters across three time points were noted in the session with the prescribed insoles (Supplementary Table S2).

Kinetic parameters

Without the prescribed insoles, the first peak of vertical GRF of the dominant side decreased significantly after 60-min walk by 11% ($p<0.001$). Meanwhile the non-dominant peak braking force increased significantly after 60-min walk by 17% ($p<0.05$) (Supplementary Table S1). No significant changes in kinetic parameters across the three time points were noted in the session with the prescribed insoles (Supplementary Table S2).

Kinematic parameters

The subjects in both walking sessions (with and without the prescribed insoles) exhibited significant reduction in dominant-side ankle plantarflexion angle during heel strike and significant increase in non-dominant side hip extension angle during terminal stance, comparing the gait after 30 minutes of treadmill walk to the baseline. Without the prescribed insoles, the changes in these two parameters were further enlarged after 60 minutes of treadmill walk (Supplementary Table S1 & S2).

Further significant changes were observed in the session without the prescribed insoles. The treadmill walk produced significant reductions ($p<0.01$) in dominant-side ankle dorsiflexion angle during terminal stance (14.6% reductions after 60 minutes of walk) and knee flexion angle during loading response (9.5% reductions after 30 minutes of walk). The non-dominant side knee flexion angle during loading response was 30.6% increased ($p<0.01$) after 60 minutes of treadmill walk. These changes were not observed when the prescribed insoles were used (Supplementary Table S1& S2).

Joint power

The subjects in both walking sessions (with and without the prescribed insoles) exhibited significant increase in non-dominant leg knee absorption power during loading response and hip power generation during initial swing after 30 minutes of treadmill walk. Without the prescribed insoles, they were further increased after 60 minutes of treadmill walk. In addition, the ankle power generation at terminal stance of the dominant leg after 30 and 60 minutes of treadmill walk were 9.1% and 12.0% lower ($p<0.05$) than the baseline, which occurred only in the session without the prescribed insoles (Supplementary Table S1& S2).

Discussion

Heel lifts and silicone insoles are commonly used to relieve plantar foot pain and reduce the strain on plantarflexors, respectively [16]. This study applied a combination of both aiming at facilitating long-distance walk of elderly people. Upon using the heel lifts and silicone insoles, improvements in perceived level of fatigue and pain were observed. Such improvements could explain the significant differences in changes in gait patterns upon walking long distances of the same group of elderly subjects between with and without the use of the prescribed insoles. Without the prescribed insoles, changes in many gait parameters upon walking long distances were significant and larger than many other studies comparing the gait differences between various interventions which reported about 5% of changes [25]. Upon using the insoles, such significant changes were no longer observed as discussed below.

Without the prescribed insoles, the subjects perceived increased level of pain in the lower limbs after the treadmill walk. Meanwhile, their stance time and the first peak of vertical GRF at the dominant side significantly reduced, which could be a strategy of relieving the increased pain. This was consistent with the finding of a previous study which indicated that patients with foot pain adjusted their gait resulting in reduced plantar force [26]. The treadmill walk also resulted in significant reductions in dominant-side plantarflexor power generation at terminal stance in the walking session without the prescribed insoles. The reduced power could be a sign of plantarflexor fatigue. A previous study on young adults have indicated that following muscle fatigue they reduced their joint power generation [27].

While reduced use of the dominant leg was found, the non-dominant leg appeared to compensate by significantly increasing knee flexion angle and absorption power during loading response and hip extension angle during terminal stance. Knee flexion during early stance, controlled by eccentric contraction (power absorption) of the quadriceps, produces anterior rotation of the tibia. This provides important source of power moving the body forwards [28]. The significant increase in non-dominant side knee flexion and absorption power angle during loading response could be a strategy of compensating the reduced ankle power generation of the dominant side. Meanwhile, the increased non-dominant side hip extension angle during terminal stance might help prepare the dominant leg to land more softly on the floor. This could be the cause of significant reduction in the 1st peak vertical GRF of the dominant side. The above compensation mechanisms were also found in other studies which involved able elderly people [24] and lower-limb amputees [29].

After using the prescribed insoles, the treadmill walk no longer led to any significant changes lower-limb pain and fatigue scores. Silicone-gel insoles acting as mechanical shock absorbers could lower the chance of getting plantar foot pain [16]. Meanwhile, the heel lift could reduce stretching of plantarflexor at each step of walking [18], potentially delaying the onset of its fatigue. While heel lifts have been clinically used to relieve Achilles tendonitis by reducing the plantaflexor stretching, little attempt has been used to reduce fatigue. This study has a limitation that the exact location of fatigue and pain were not identified. Future studies can conduct clinical assessments to accurately locate pain and fatigue locations among older people walking long distances.

With improvements in lower-limb pain and fatigue scores, the compensatory movements became less obvious in the session with the use of the prescribed insoles. Gait data showed that there were no longer significant changes in stance time, ground reaction forces and plantarflexor and knee extensor power across the three time points of treadmill walk while using the prescribed insoles. There were still a few significant changes in some joint angles and power. While these changes occurred after 30 minutes of walk, there were no significant differences between the baseline and 60 minutes of walk in all measured parameters. Before the treadmill walk, the heel lift significantly reduced the plantarflexion angle when the foot just started to lie flat on the ground following heel strike (first peak of the ankle angle-time curve). This is an interesting finding as raising the heel could tend to increase plantarflexion angle. The reduced plantarflexion could be caused by increased anterior rotation of the tibia, a movement which help propel the body forwards [28].

Following improvements in gait, pain and fatigue perception, the prescribed insoles significantly reduced the perceived intensity of walking (physical exertion) after both 30 and 60 minutes of treadmill walk. Orthopaedic insoles are commonly used to improve comfort, alter gait patterns and treat a number of lower extremity aliments [15-

18]. To the best knowledge of the authors, this is the first study which shows the potential of orthopaedic insoles of facilitating long-distance walking of elderly people. While this study showed 20-mm heel lifts together with a 3mm thick full-length silicone insoles offer some benefits in long-distance walking, special care has to be taken as some studies have indicated that raised heels could have negative effects on gait [30]. Although previous studies, as reviewed in one article [30], mainly focused on high-heel shoes with heel raises clearly higher than the ones used in this study, future research should identify an optimum heel height specifically for elderly people. Attention should also be paid to the fact that this study had certain subject inclusion criteria. The findings of this study should not be applied to members of the public who are out these inclusion criteria. In addition, the long-term impact of this footwear modification on health and quality of life has not been investigated, which warrants future studies.

Conclusions

Heel lifts and silicon insoles are generally used to relieve plantar pain and reduce strain of plantar flexors in patients. This study showed they could significantly improve subjective perception of physical exertion, pain and fatigue of elderly people, who did not have obvious lower-limb problems, performing long-distance walking. Objective gait anaylsis showed that without using the prescribed insoles, long-distance walking produced significant reductions in stance time, vertical ground reaction force, ankle dorsiflexion angle and ankle power generation of the dominant leg. Such significant reductions were no longer observed in the same group of subjects upon using the prescribed insoles. This footwear modifcation could be a biomechanical solution to facilitate long-distance walking of older adults. Future studies should investigate its long-term impact on health and quality of life.

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Declaration of interest

Conflicts of interest: none.

Figures Legends

Figure 1: Visual Analogue Scale (schematic) assessing perceived level of pain and fatigue

Figure 2: Average BORG CR10 scores in subjects with and without the prescribed insoles at the baseline, 30-min and 60-min walking.

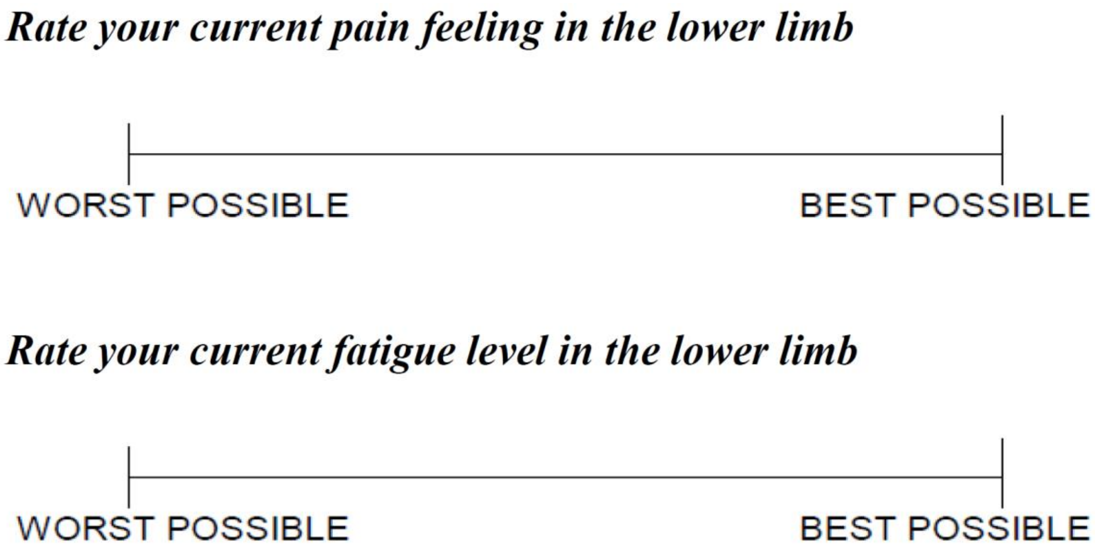
Figure 3: Dominant side kinematic/kinetic data along a gait cycle without the prescribed insoles (averaged across all subjects)

Figure 4: Dominant side kinematic/kinetic data along a gait cycle with the prescribed insoles (averaged across all subjects)

Table 1. Borg CR10 Scale for perceived exertion.

✓	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: Visual Analogue Scale (schematic) assessing perceived level of pain and fatigue



Rate your current pain feeling in the lower limb

WORST POSSIBLE BEST POSSIBLE

Rate your current fatigue level in the lower limb

WORST POSSIBLE BEST POSSIBLE

Figure 2: Average BORG CR10 scores in subjects with and without the prescribed insoles at the baseline, 30-min and 60-min walking.

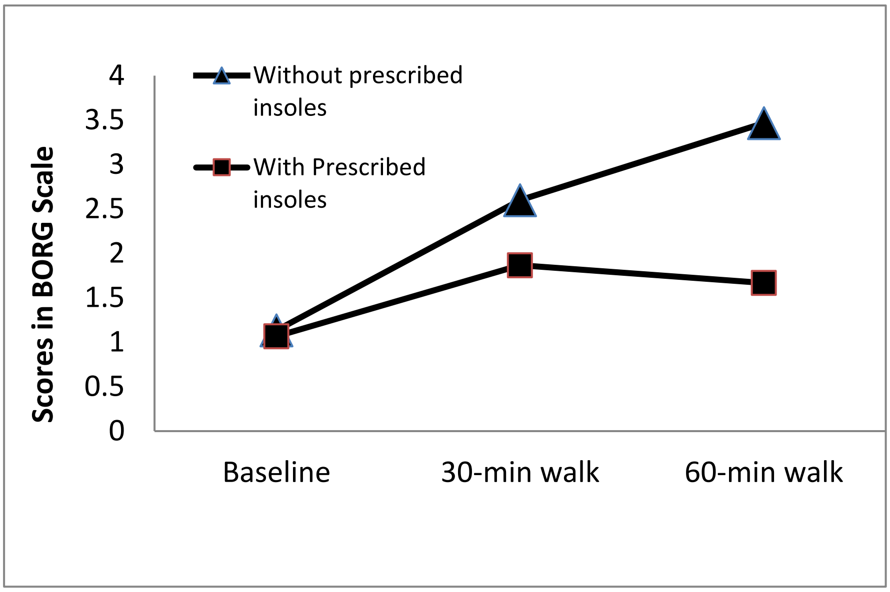


Figure 3: Dominant side kinematic/kinetic data along a gait cycle without the prescribed insoles (averaged across all subjects)

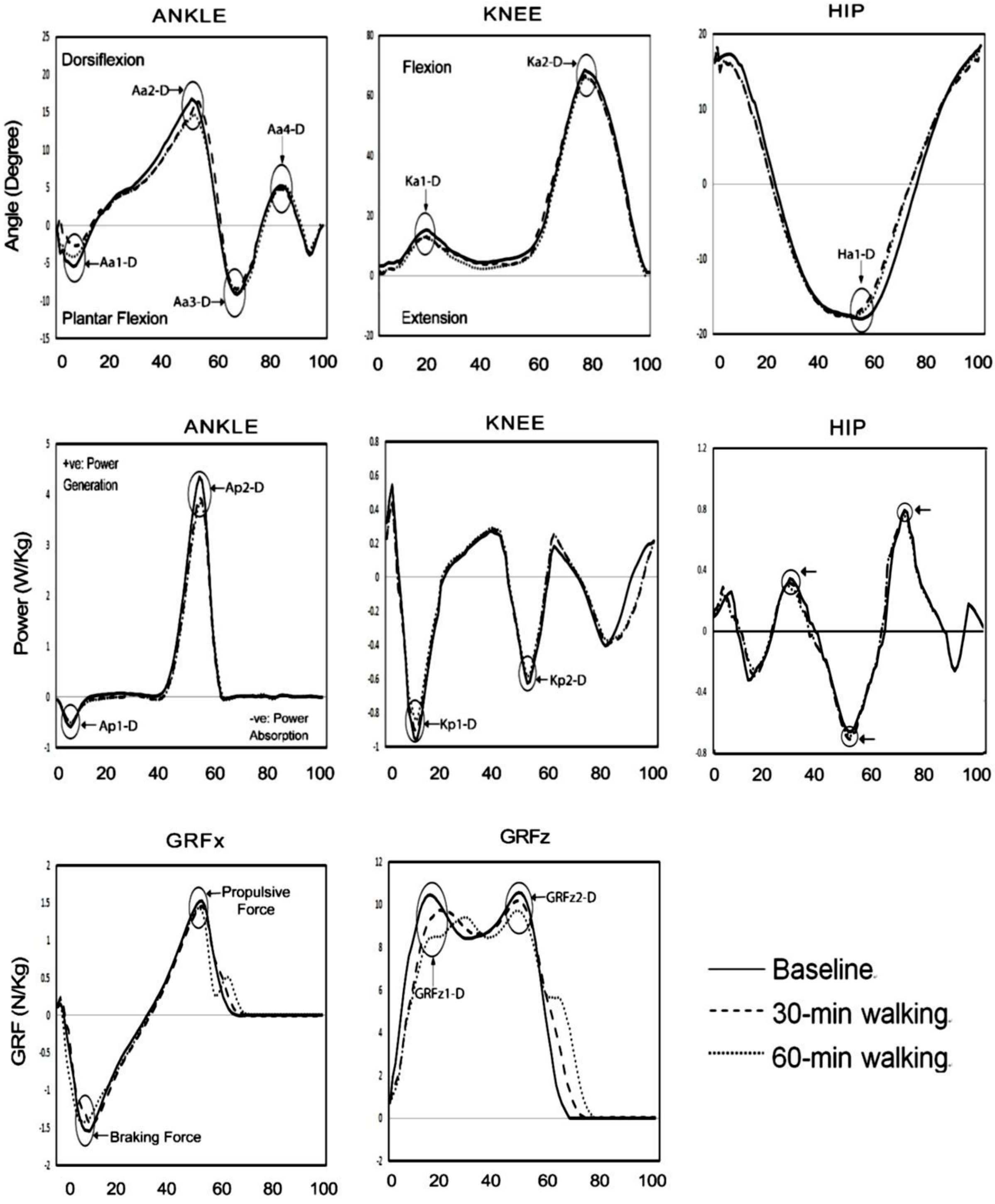


Figure 4: Dominant side kinematic/kinetic data along a gait cycle with the prescribed insoles (averaged across all subjects)