Freedom Shoes: analysis of gait

A study performed for Freedom Shoes Ltd

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SHARPENS YOUR THINKING

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1.0 Introduction

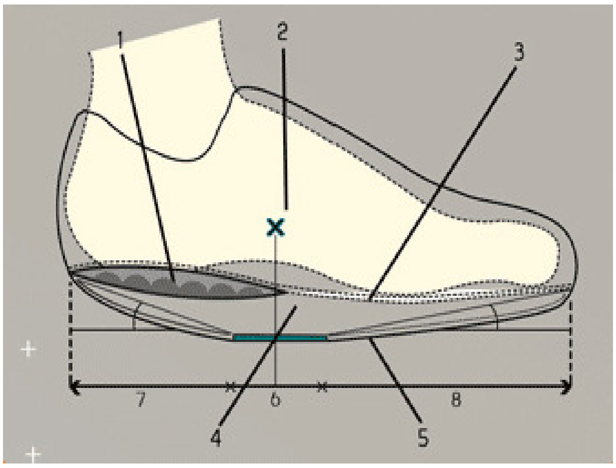
This study was commissioned by Freedom Shoes Ltd (London, UK) and details research performed at and by The Centre for Sport and Exercise Science, Sheffield Hallam University. This independent research presents a scientific approach to the evaluation of gait, the results of which will inform the reader regarding the effect of Freedom Shoes on normal gait characteristics. The advanced biomechanics technology used will help ascertain whether wearing Freedom Shoes affects

- gait kinematics
- gait kinetics
- gait muscle activation patterns

It is documented that the use of an unstable shoe construction changes the kinematics, kinetics and muscle activation patterns associated with normal gait (Nigg *et al.*, 2006; Romkes *et al.*, 2006). Both Nigg (2004) and Naik *et al.* (2004) found that the use of the Masai Barefoot Technology (MBT) shoe promoted a reduction in the joint loading associated with walking and significant changes in kinematics at the ankle and knee. Changes in muscle activation patterns have also been observed during gait in unstable footwear (Romkes *et al.* 2005; Naik *et al.* 2004).

It is claimed by manufacturers, that these changes in gait parameters are related to a reduction in stress on the body, reduction in potential back problems, help with recovery from injury and toning and shaping of the body. These claims are supported to some degree by the work of Nigg *et al.* (2006) who observed a reduction in pain in osteoarthritis patients following use of unstable footwear when compared to a control group.

The key principle of Freedom Soles is an inbuilt pivot area in the foot sole (Figure 1), this pivot area, combined with a soft heel insert and a special rounded mid-sole creates an inbuilt instability that challenges the muscles to maintain control over locomotion rather than relying on the stability provided by a conventional shoe. Freedom Soles are designed to be less unstable than many of the unstable shoes currently on the market however be unstable enough to encourage a gentle postural sway during standing..



- 1. Soft heel insert (TPU material)
- 2. Shoe uppers
- 3. Soft shaped insole
- 4. PU mid-sole

- 5. Outer sole
- 6. Pivot area
- 7. Rounded heel
- 8. Rounded toe

Figure 1: The Freedom Soles Shoe

The current study aims to identify changes in gait characteristics as a result of wearing the Freedom Soles shoe. If these changes are deemed similar to those of other manufacturers it could be assumed that the same benefits can be gleaned when using a shoe that is less stable than traditional shoes yet more stable than unstable shoes currently on the market.

2.0 Methods

Participants

Six Female and four male participants (mean ± SD: age 27 ± 5.7 years, stature 1.73 ± 0.03 m, body mass 68.5 ± 5.85 kg) volunteered to take part in the study. Each was physically active and free from musculoskeletal injury at the time of testing. The University's Ethics Committee approved the procedures, and written informed consent was gained from participants before data collection.

Experimental set-up

All kinematic data were collected using a twelve-camera digital motion capture system (Motion Analysis Corporation, Santa Rosa, CA, USA) sampling at 200 Hz.

The twelve cameras of the motion capture system were placed in optimal positions around a calibrated measurement volume of dimensions 5.0 × 2.0 × 3.0 m in the *x*, *y* and *z* directions respectively. The measurement volume was made this size to incorporate a step both before and after the stance phase on the Kistler Type 9281CA force platform (Kistler Instrumente AG Winterthur, Switzerland) which was embedded in the laboratory floor and covered with a surface common to the entire laboratory. The force platform sampled data at 1000 Hz and was time-synchronised with the motion capture system.

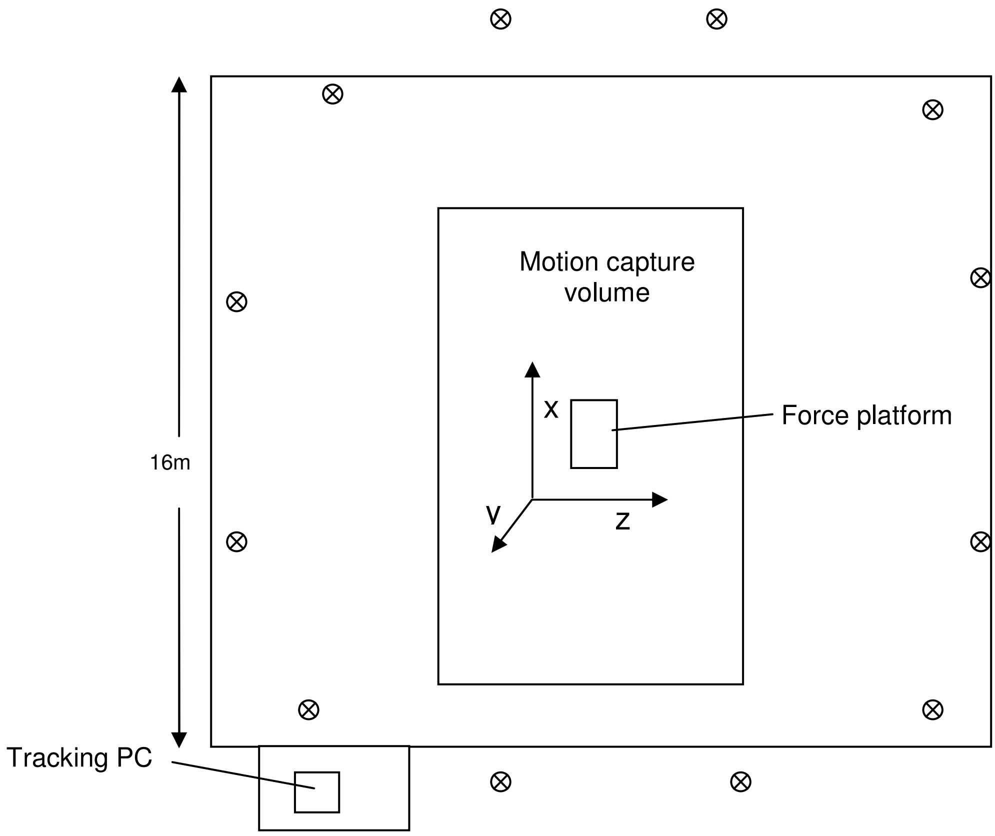


Figure 2.1: The experimental setup; ⊗ - Digital motion capture camera.

Twenty two retro-reflective markers (12.5 mm diameter) were attached to the participant's right leg, pelvis and trunk. Markers were attached to the paricipants' right 2nd and 5th metatarsal head (closest approximation on the shoe), posterior aspect of the calcaneus (closest approximation on the shoe), lateral and medial malleolus, lateral and medial femoral epicondyle, anterior superior iliac spine, sacrum, right and left acromion process, sternal notch, xiphoid process, 7th cervical and 8th thoracic vertebrae. Six further markers were attached to two heat moulded plastic plates and mounted to the right shank and thigh.

Following suitable skin preparation in accordance with European recommendations for surface electromyography (Hermens *et* al., SENIAM, 1999), surface EMG electrodes were positioned on Gastrocnemius, Gluteus Maximus, Biceps femoris and Multifidus on the right side.

Static calibration trial

For each condition a static calibration trial was collected to allow for correct anatomical reference frame alignment. Kinematic data were collected for 5 seconds with the participant in the calibration standing position. Following this trial the lateral and medial malleolus and lateral and medial femoral epicondyle markers were removed.

Data collection session

Prior to testing, participants were provided with a pair of Freedom Soles shoes and given a 30 minute instruction session conforming to manufacturer's specifications. Participants were required to use the Freedom Shoes as much as possible during the subsequent two weeks prior to the start of testing in an attempt to further familiarise themselves with the suggested walking technique.

After preparation and attachment of the marker set and EMG electrodes, the participant was required to traverse the laboratory, in the positive x direction (see fig 2.1), at their preferred speed while making contact with the force platform with the right foot. Each participant completed twelve 'good' trials in both the Freedom Shoes and normal shoe conditions. The participant's normal training shoe was used as the control shoe for the purposes of the study.

Trials were accepted when the whole of the participant's foot contacted the force platform, without any obvious alterations to their gait. Participants were permitted as many practice trials as required to become able to consistently achieve this prior to the onset of data collection. During each trial, five seconds of kinematic data were collected using the motion capture system along with the kinetic data from the force platform and EMG signals.

Quiet standing trials were captured for the normal and Freedom Shoes condition. This involved the participant standing facing the negative z direction (see fig 2.1) on the same Kistler Type 9281CA force platform sampling at 100Hz for 60 seconds. Participants were instructed to stand "normally" while looking straight ahead at a blank wall.

Data analysis

Kinematics

The three-dimensional coordinate data were filtered using a second order low-pass Butterworth filter; a cut-off frequency of 6 Hz was used selected through visual inspection of the fit. Hip, knee and ankle Joint Coordinate System (JCS) angles (Grood and Suntay, 1983) were then calculated using Visual 3D software (C-Motion Inc, Rockville, MD, USA). The three-dimensional angles of the pelvis and trunk were defined relative to the global coordinate system and were also calculated using the Visual 3D software.

The resulting angular displacement profiles were then cropped to the length of one foot contact and interpolated to 101 data points. The vertical component of the ground reaction force was used to determine foot contact events - thresholds of 20 N and 10 N were used to determine foot-strike and toe-off respectively.

Dependent variables were taken from the kinematic data. These included the degree of angular displacement at the ankle, knee and hip joints in the sagittal plane at foot-strike and toe-off and times of maximum and minimum values. Sagittal plane trunk and pelvis angles, relative to the global coordinate system, were also recorded at the times of these events.

Ground reaction force

Further dependent variables were taken from the ground reaction force data. These included; peak vertical force in the first half of stance (impact peak), peak vertical force in the second half of stance (propulsive peak), maximum propulsive force and maximum braking force.

Kinetics

The Visual 3D software (C-Motion Inc, Rockville, MD, USA) was used to calculate internal resultant joint moments using an inverse dynamics technique. Dependent variables for the kinetics data included the resultant joint moment at the ankle, knee and hip joints in the sagittal plane at foot-strike and toe-off. Furthermore, maximum and minimum sagittal plane joint moments were recorded at the ankle, knee and hip joints.

Muscle Activation

EMG data were analysed using Visual 3D software (C-Motion Inc, Rockville, MD, USA). A data smoothing technique was performed using a low pass Butterworth filter (400Hz) to filter out any high frequency component not associated with muscle electrical activity, and a high pass Butterworth filter (15Hz) to remove any movement artefact. A second low pass Butterworth filter was used to smooth the data to highlight changes in amplitude of the electrical signal.

Standing Trials

The anterior/posterior and medial/lateral centre of pressure were calculated using Visual 3D software (C-Motion Inc, Rockville, MD, USA). Data were filtered using a second order low-pass Butterworth filter; a cut-off frequency of 6 Hz was used and was selected through visual inspection of the fit. Standard deviation, range and total path length were calculated and centre of pressure data were then graphed in Microsoft Excel software (Microsoft Corp, 2003).

Statistical analysis

Firstly, the data for each dependent variable were screened to ensure that it did not violate the assumptions of *t*-test. A series of paired t-tests were performed on the data from both conditions with the alpha level of significance set at 0.05 for all statistical tests. Muscle activation graphs were visually inspected and the stance phase broken down into four equal parts, the mean and percentage difference in amplitude of the electrical signal for each of the four phases of stance were calculated for both the Freedom Shoes and normal shoe conditions.

3.0 Results and Discussion

Kinematics

Comparison of walking in normal and Freedom Shoes suggested that there were some differences in gait kinematics.

The use of Freedom Shoes elicited a decrease in the forward lean of the trunk (figure 3.1) suggesting participants adopted a more upright posture when using the Freedom Shoes. Although this difference was only statistically significant ($p < 0.05$) at the point of heel strike, figure 3.1 shows a trend for this decrease in trunk angle to remain throughout stance.

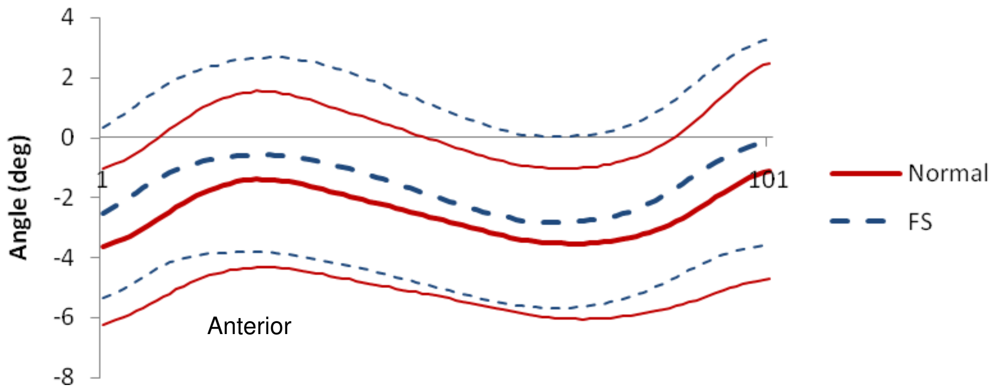


Figure 3.1: Mean ± SD across all subjects; Trunk angle during the stance phase of gait for the Freedom Shoes and normal condition.

Participants also exhibited a significant decrease ($p < 0.05$) in hip flexion at heel strike (Figure 3.2) which could be consistent with a shortening of the stride during Freedom Shoes gait.

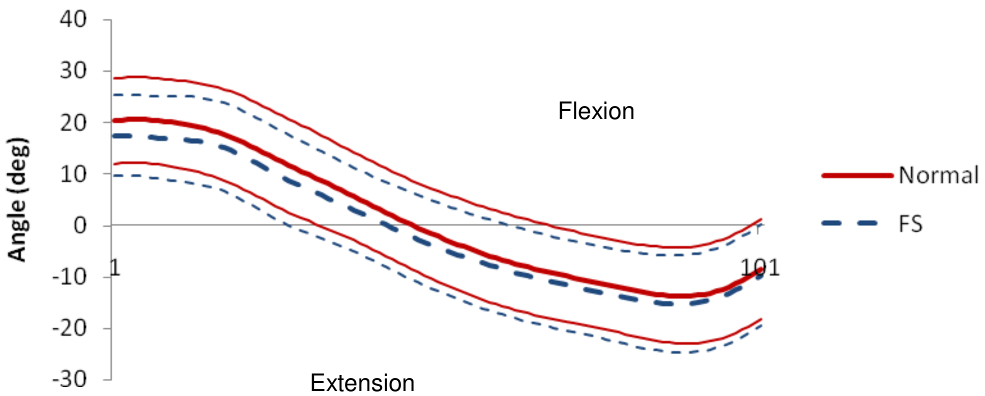


Figure 3.2: Mean ± SD across all subjects; Hip angle during the stance phase of gait for the Freedom Shoes and normal condition.

There was no significant change in knee angle as a result of wearing Freedom shoes although there was a trend towards a reduction in knee flexion during mid stance (figure 3.3).

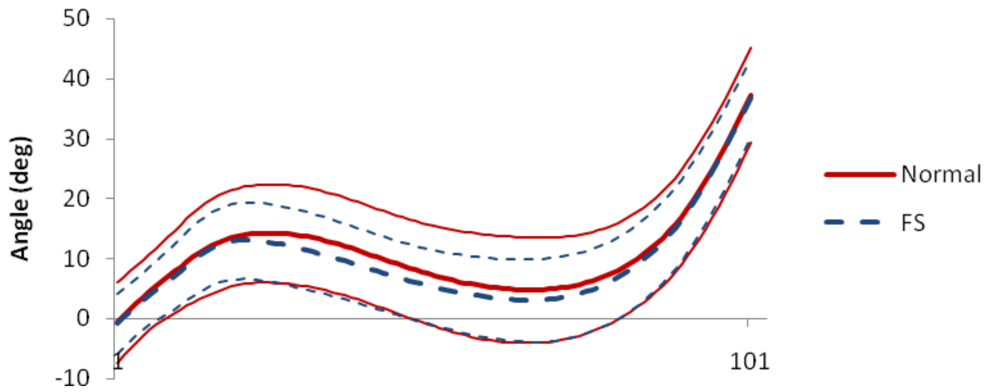


Figure 3.3: Mean ± SD across all subjects; Knee angle during the stance phase of gait for the Freedom Shoes and normal condition.

There were significant differences in the ankle angle at toe off ($p < 0.05$) where the ankle was in a more plantar-flexed position during normal gait than Freedom Shoes gait. There were also significant differences ($p < 0.05$) following initial contact where the Freedom Shoes gait exhibited a reduction in plantar-flexion (Figure 3.2).

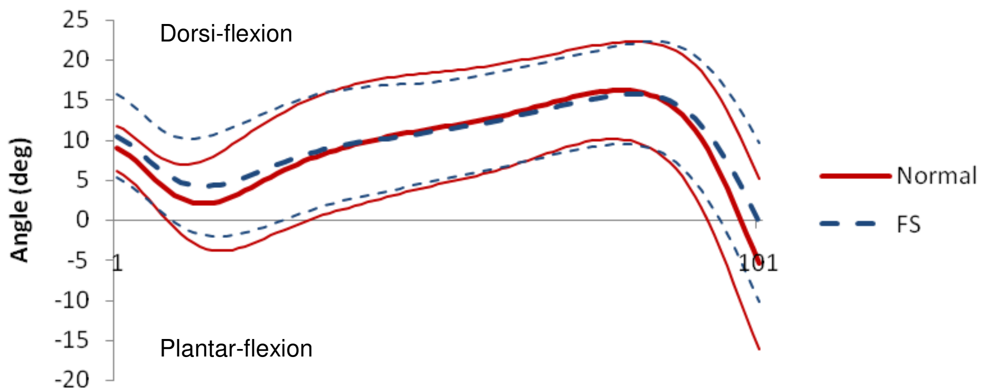


Figure 3.4: Mean ± SD across all subjects; Ankle angle during the stance phase of gait for the Freedom Shoes and normal condition.

At the pelvis there were no significant differences in the sagittal plane kinematics however there is a trend towards a reduction in anterior tilt of the pelvis at heel strike (figure 3.5).

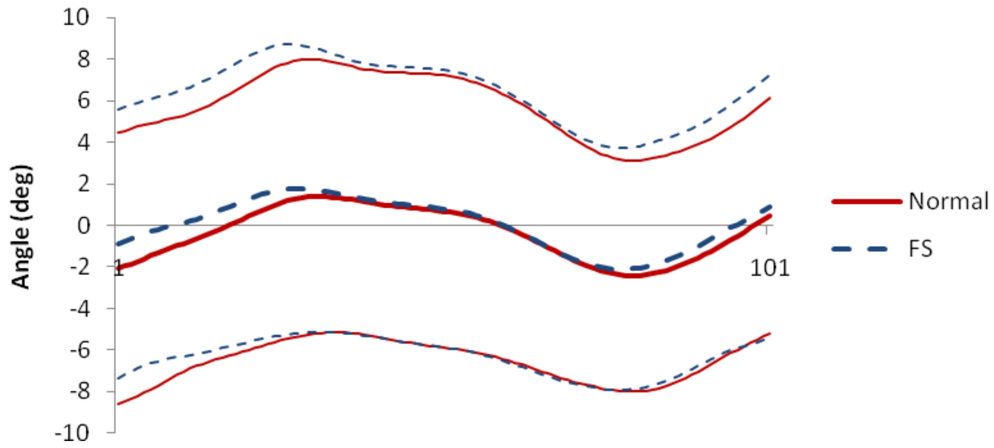


Figure 3.5: Mean ± SD across all subjects; Pelvis angle during the stance phase of gait for the Freedom Shoes and normal condition.

Main finding: Freedom Shoes alter certain gait kinematics during the stance phase of gait; most notably changes were seen in the trunk, hip and ankle. Most of these changes could be attributed to the shorter stride length promoted by the use of Freedom Shoes.

Ground Reaction Force

Analysis of the vertical ground reaction forces (Figure 3.8) showed a significant ($p < 0.05$) decrease in the vertical impact and active peaks during stance.

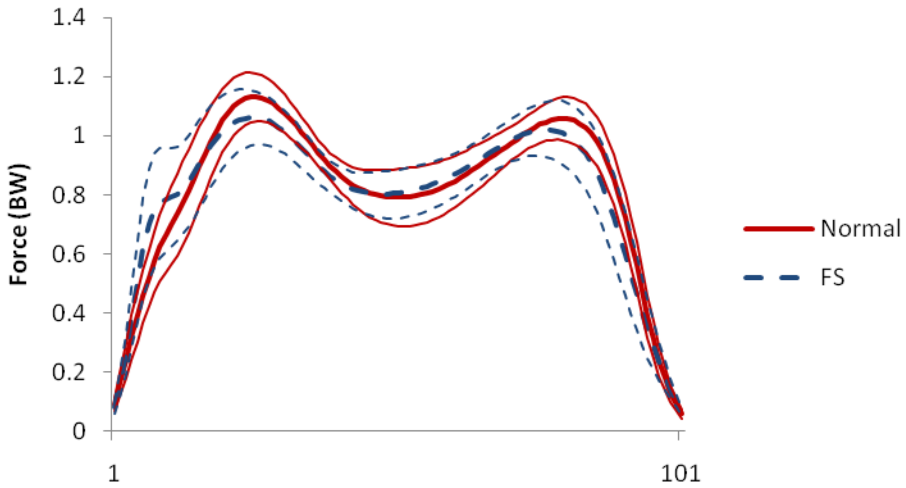


Figure 3.8: Mean ± SD across all subjects; Vertical ground reaction force trace during the stance phase of gait for the Freedom Shoes and normal condition.

In the anterior - posterior direction (figure 3.9) the Freedom Shoes promoted a significant ($p < 0.05$) reduction in the peak propulsive forces experienced during gait. There is also a decrease in the impulse (area under the graph) experienced during the Freedom Shoes condition; this is likely to be due to the shorter stride length.

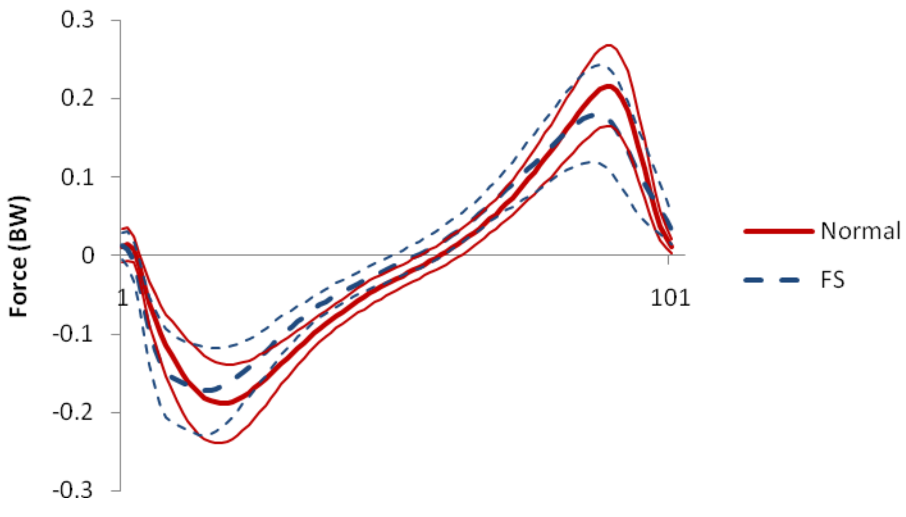


Figure 3.9: Mean ± SD across all subjects; Anterior-Posterior ground reaction force trace during the stance phase of gait for the Freedom Shoes and normal condition.

Main finding: Freedom Shoes promote a decrease in the impact and active vertical ground reaction force peaks and a decrease in the propulsive (forward) force during gait. This could most likely be attributed to the associated decrease in stride length.

Kinetics

Analysis of joint kinetics during walking showed several differences in the joint moments experienced during the Freedom Shoes and normal shoe conditions. At the hip (Figure 3.5), Freedom Shoes produced significantly lower flexion moments ($p < 0.05$) during terminal stance and at toe off as a result of the decrease in stride length.

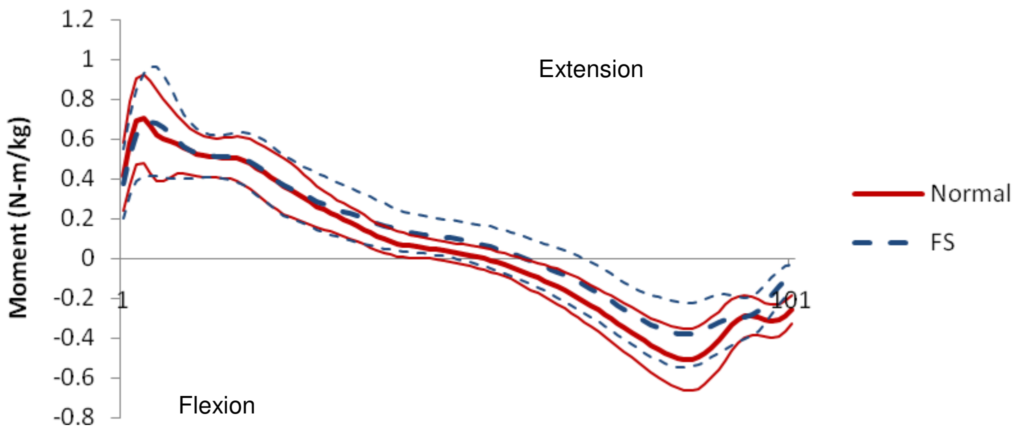


Figure 3.5: Mean ± SD across all subjects; Hip flexion/extension moment during the stance phase of gait for the Freedom Shoes and normal condition.

The knee (Figure 3.6) experienced significantly lower extension moments ($p < 0.05$) during weight acceptance. There was also a significant ($p < 0.05$) reduction in extension moment at toe off probably due to the reduced stride length. Freedom Shoes also elicited an increase ($p < 0.05$) in the knee flexion moment during terminal stance.

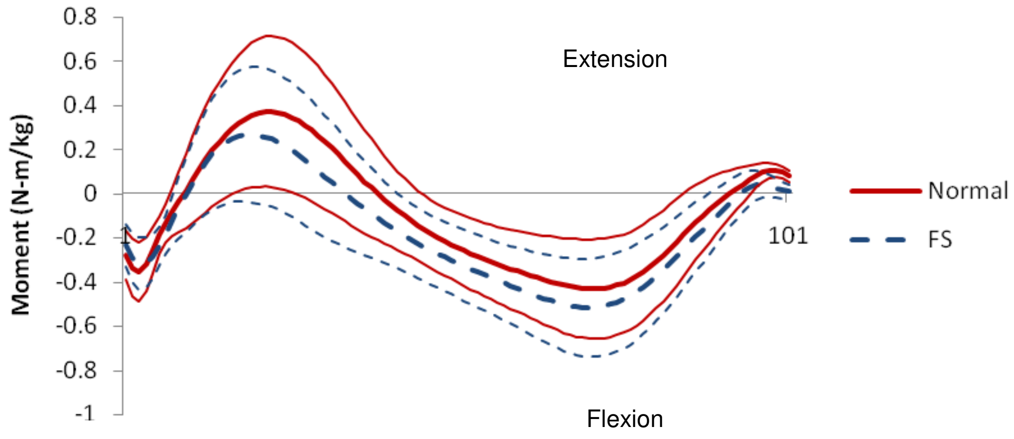


Figure 3.6: Mean ± SD across all subjects; Knee flexion/extension moment during the stance phase of gait for the Freedom Shoes and normal condition.

At the ankle (Figure 3.7) there were significant (p < 0.05) reductions in the dorsi-flexion moments experienced during initial contact in the Freedom Soles condition compared to the normal condition. The rounded sole of the Freedom Shoe means that eccentric control of plantar flexion from heel heel strike to mid-foot contact is not required. There was also a significant (p < 0.05) difference in the joint moment at toe off.

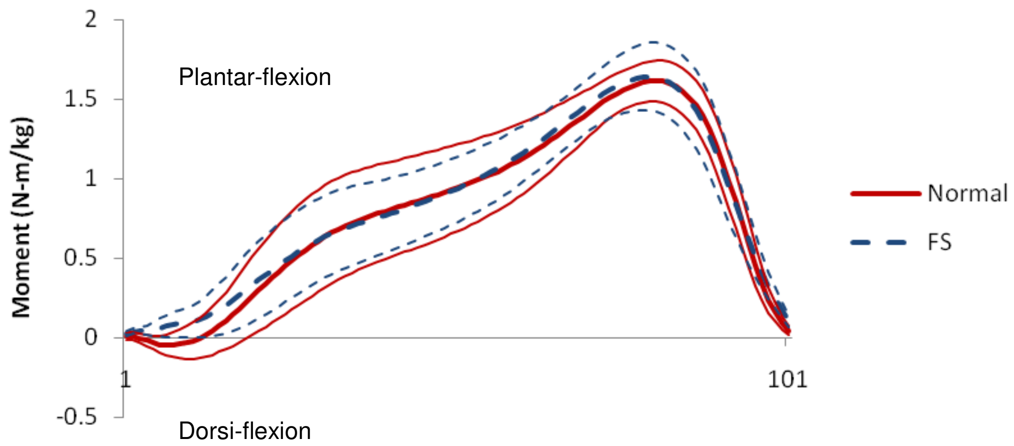


Figure 3.7: Mean ± SD across all subjects; Ankle Plantar-flexion/dorsi-flexion moment during the stance phase of gait for the Freedom Shoes and normal condition.

The changes in kinetics can be attributed to the change in gait kinematics and the reduced vertical ground reaction forces experienced when walking in Freedom Shoes compared to normal shoes.

Main finding: When walking in Freedom Shoes, participants experienced reduced dorsi-flexion moments at the ankle, reduced hip flexion moments during terminal stance and at toe off and decreased extension moments at the knee during weight acceptance and at toe off. The knee flexion moment during terminal stance is greater when wearing Freedom shoes when compared to normal shoes.

EMG

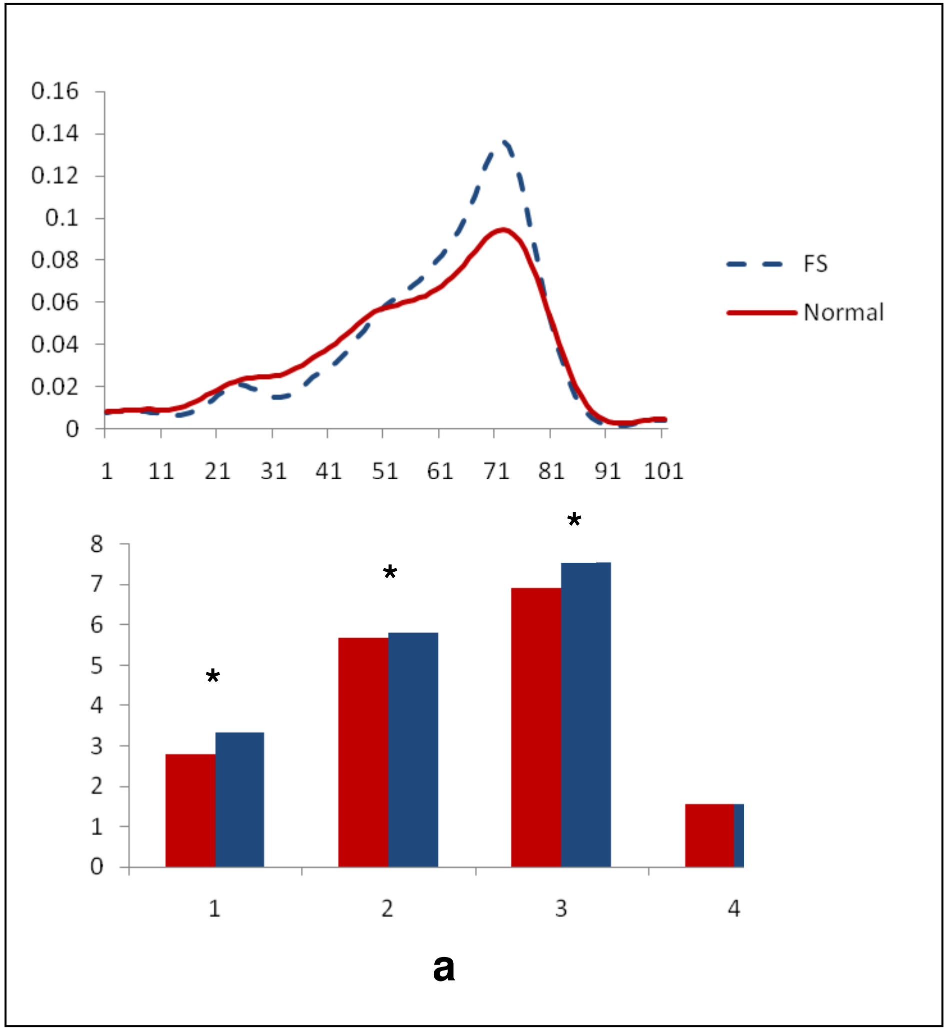
Freedom Shoes elicit a decrease in the electrical activity (motor unit recruitment) at certain times during the stance phase of the gait cycle. These are related to the kinematics of Freedom Shoes Gait and are presented in Table 3.1.

Heightened activity ($p < 0.05$) in the gastrocnemius (figure 3.10a) occurs throughout stance with a particular increase during initial contact as the lower leg has to work to control the instability of the Freedom Shoe. In the other three muscles tested there was a marked decrease in muscle activity throughout stance, most notably in the multifidus (fig 3.10d) muscle in the lower back where Freedom Shoes promoted an average 43.7 % decrease in electrical activity ($p < 0.05$). This is probably attributable to the reduction in forward lean of the trunk and anterior pelvic tilt associated with Freedom Shoes gait and the reduced requirement for muscle activity in order to remain upright. This reduction in multifidus activity may reduce the fatigue implications of gait and result in a reduction in the stress on the lower back.

	Percentage of Stance Phase				
	25	50	75	100	0-100
Gastroc Norm	2.788647	5.676262	6.908232	1.557086	
Gastroc FS	3.326981	5.80627	7.545454	1.563034	
% Change	19.3*	2.29*	9.22*	0.38	7.80*
Ham Norm	2.517329	1.688958	1.626754	3.605121	
Ham FS	2.231305	1.552369	1.056681	1.614817	
% Change	-11.4*	-8.09	-35.0*	-55.2*	-27.4*
Glute Norm	4.745324	1.672802	1.374142	1.025065	
Glute FS	3.92755	1.457001	1.070908	0.639397	
% Change	-17.2*	-12.9*	-22.1*	-37.6*	-22.5*
Mult Norm	8.036187	4.321729	4.340141	5.616422	
Mult FS	3.991759	2.385851	2.642815	3.341114	
% Change	-50.3*	-44.8*	-39.1*	-40.5*	-43.7*

Table 3.1: Percentage change in electrical activity across all trials for all participants; * signifies significance ($p < 0.05$).

Main finding: The Freedom Shoes promoted a significant ($p<0.05$) reduction in muscle activity across three of the four muscles tested, including a 43% decrease in muscle activity in the Multifidus muscle in the lower back. This is a result of the more upright trunk posture during stance.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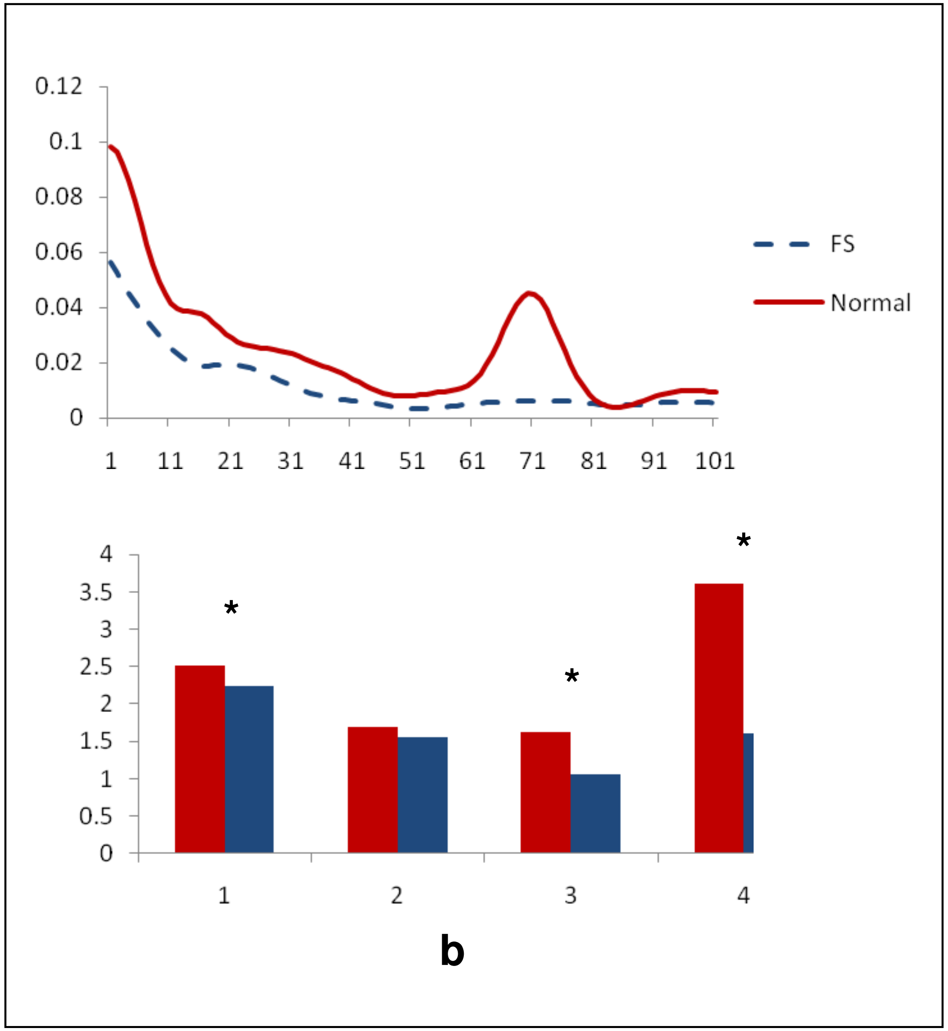
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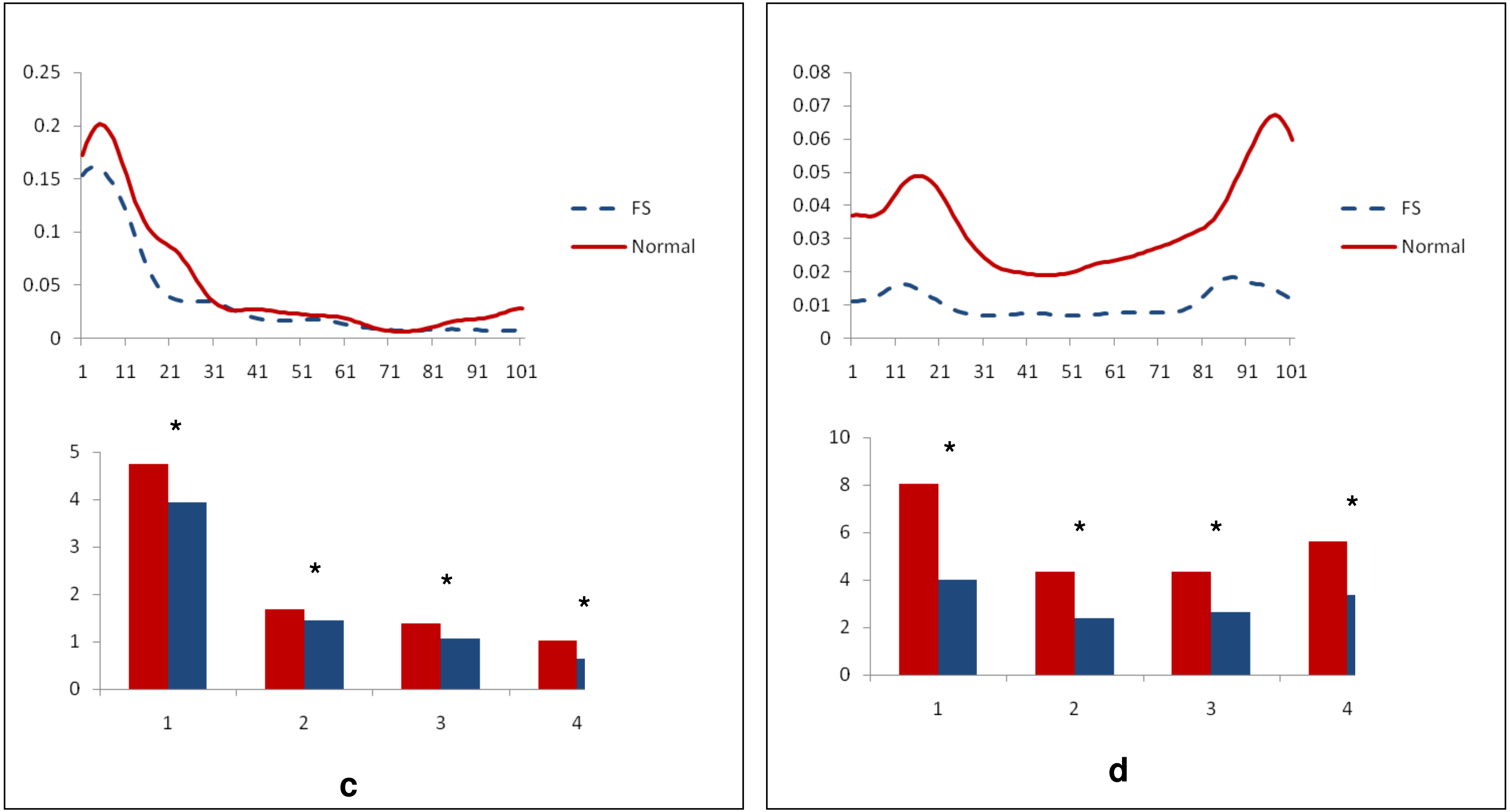

Figure 3.10: Representative and average over four phases of stance phase, electrical activity at the gastrocnemius (a); hamstring (b); Gluteus maximus (c);multifidus (d) of normal and Freedom Shoes gait. * signifies significance ($p < 0.05$).

Postural Sway

Although none of the findings were statistically significant, analysis of the centre of pressure during 60 seconds of quiet standing suggested a trend towards less sway during standing when wearing normal shoes compared to Freedom Soles. This was evident in both the anterior/posterior and medial/lateral directions (figure 3.11) where the mean path length, range and standard deviation of the centre of pressure were all greater when standing in Freedom Shoes compared to normal shoes (table 3.2). As would be expected due to the shape of the sole, the centre of pressure excursion in the anterior/posterior direction was greater than the medial/lateral direction.

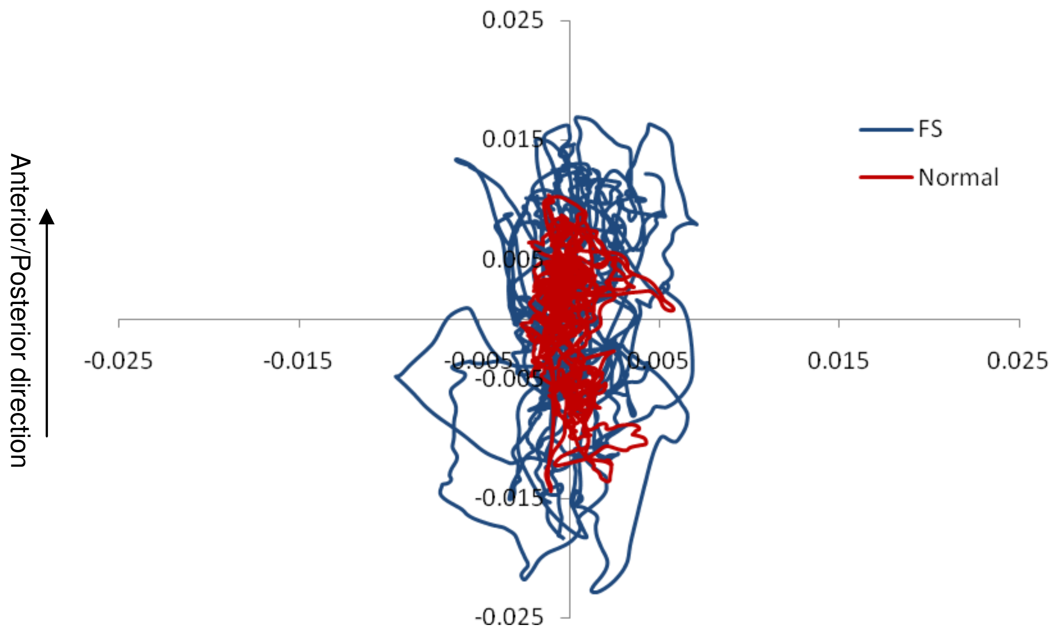

Figure 3.11: Representative centre of pressure distribution during 60s quiet standing in normal shoes and Freedom Shoe conditions.

	FS		Norm	
	m/l	a/p	m/l	a/p
Path length (m)	0.300	0.543	0.270	0.414
Range (m)	0.014	0.032	0.012	0.023
Stdev (m)	0.002	0.006	0.002	0.004

Table 3.2: Mean path length, range and standard deviation of the centre of pressure during 60s quiet standing in Freedom Shoes and normal shoes.

4.0 Summary

Freedom Shoes do have an effect upon the lower limb kinematics and kinetics of gait for the participants used during this study.

Freedom Shoes promote a more upright trunk posture, and although not within the scope of this research, the probable effect is a shift in the centre of mass position closer to the base of support, possibly aligning the body more optimally for locomotion. This upright posture and changes in the kinematics of the hip, knee and ankle coupled with a decrease in vertical ground reaction force impact and active peaks result in a decrease in some of the joint loading experienced at the hip, knee and ankle.

These results could be largely attributed to a decrease in stride length inherent in the Freedom Soles walking technique.

Freedom Shoes gait also elicited decreases in muscle activity in the multifidus muscle potentially reducing the fatiguing effect of walking and the subsequent stress on the lower back. This is probably a result of the more upright trunk posture during Freedom Shoes gait.

During quiet standing, the centre of pressure results suggest that Freedom Shoes are less stable than normal shoes however not significantly.

In summary, Freedom Shoes elicit similar characteristics as other shoes of unstable construction; these include some reduction in joint loading, altered kinematics and muscle activation, while still maintaining enough stability to prevent excess postural sway during standing.