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Changes in Plantar Pressure, Force and Contact Area when Carrying Incremental Loads among Adults with and without Low Back Pain

(Perubahan padaTekanan Plantar, Kekuatan dan Permukaan Sentuhan ketika Mengangkat Beban dalam Kalangan Orang Dewasa Sihat dan Pesakit Sakit Belakang)

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ABSTRACT

Plantar pressure, force and contact area information may provideinsights regarding stresses imparted to the foot when performing functional tasks. There is limited information regarding plantar pressure, force and contact area when carrying incremental loads (no load, 5 kg, 7.5 kg and 10 kg) using one hand between adults with and without low back pain (LBP). The aim of our study was to investigate the changes in the plantar pressure, force and contact area when carrying incremental loads (no load, 5 kg, 7.5 kg and 10 kg) using one hand between adults with and without low back pain (LBP). A total of 20 adults with non-specific LBP and 20 matched individuals without LBP were recruited according to the predefined recruitment criteria. Plantar pressure (PP), maximum force (MF) and contact area (CA were measured in standing position and during walking while carrying incremental loads (no load, 5 kg, 7.5 kg and 10 kg) using their right hand on a Matscan pressure assessment system. A two-way mixed analysis of variance (group × load) was conducted to analyse the data. No significant main effectof group was demonstrated on both the right and left foot during standing (PP: $p = 0.74$, $p = 0.32$; MF: $p = 0.17$, $p = 0.67$; CA: $p = 0.25$, $p = 0.24$) and walking (PP: $p = 0.61$, $p = 0.48$; MF: $p = 0.19$, $p = 0.06$; CA: $p = 0.16$, $p = 0.26$. Similarly, there was no interaction effect between the loads and groups on the PP ($p = 0.89$, $p = 0.47$), MF ($p = 0.76$, $p = 0.83$) and CA ($p = 0.88$, $p = 0.20$) on theright and left foot, respectively during standing. However, a significant interaction effect ($p < 0.05$), between the loads and groups was demonstrated on the PP, MF and CA on the left foot during walking. The results of our study suggest that stresses imparted to the foot alters during dynamic postures and this may be a compensatory mechanism. Plantar pressure, force and contact area were similar in adults both with and without LBP when standing and walking. Further biomechanical information that includes both kinematic and kinetic data in lumbopelvic and lower limbs in relation to the foot may be required to justify for prevention and management strategies among adults with LBP.

Keywords: Plantar pressure; maximum force; contact area; low back pain; loads

ABSTRAK

Tekanan, daya maksimum dan permukaan sentuhan plantar memberikan maklumat penting berkaitan tekanan di kaki ketika melakukan aktiviti fungsian. Maklumat tentang tekanan, daya maksimum dan permukaan sentuhan plantar apabila mengangkat beban yang meningkat (no load, 5 kg, 7.5 kg and 10 kg) menggunakan satu tangan di kalangan orang dewasa dengan dan tanpa sakit belakang adalah terhad. Kajian ini bertujuan untuk mengenal pasti perubahan dalam tekanan, daya maksimum dan permukaan sentuhan plantar apabila mengangkat beban yang meningkat (tiada beban, 5 kg, 7.5 kg dan 10 kg) menggunakan satu tangan di kalangan orang dewasa dengan dan tanpa sakit belakang. Sejumlah20 orang dewasa dengan dan 20 orang tanpa sakit belakang tidak spesifik, yang dipadankan telah direkrut berdasarkan kriteria pengambilan yang telah ditetapkan. Tekanan, daya maksimum dan permukaan sentuhan plantar telah diukur dalam kedudukan berdiri dan semasa berjalan sambil mengangkat beban yang meningkat dengan tangan kanan menggunakan sistem penilaian tekanan Matscan. Analisa varian dua hala tercampur (kumpulan × beban) telah dijalankan untuk menganalisa data kajian.Tiada sebarang kesan utama yang signifikan di antara kumpulan pada plantar kaki kanan dan kiri ketika berdiri (tekanan: $p = 0.74$, $p = 0.32$; daya maksimum: $p = 0.17$, $p = 0.67$; permukaan sentuhan: $p = 0.25$, $p = 0.24$) dan ketika berjalan (tekanan: $p = 0.61$, $p = 0.48$; daya maksimum: $p = 0.19$, $p = 0.06$; permukaan sentuhan: $p = 0.16$, $p = 0.26$). Dapatan yang serupa juga diperolehi pada kesan interaksi di antara beban dan kumpulan pada tekanan ($p = 0.89$, $p = 0.47$), daya maksimum ($p = 0.76$, $p = 0.83$) dan permukaan sentuhan ($p = 0.88$, $p = 0.20$) pada plantar kaki kanan dan kiri, masing-masing. Walau bagaimanapun, ketika berjalan, kesan interaksi yang signifikan ($p < 0.05$) di antara beban dan kumpulan dapat diperhatikan pada tekanan, daya maksimum dan permukaan sentuhan plantar pada kaki kiri. Hasil kajian ini menunjukkan bahawa tekanan pada kaki mengalami perubahan semasa postur dinamik dan ini mungkin disebabkan oleh mekanisma kompensasi. Tekanan, daya maksimum dan permukaan sentuhan plantar adalah sama di kalangan orang dewasa dengan dan tanpa sakit belakang ketika berdiri dan berjalan. Maklumat *biomekanik yang lebih lanjut yang merangkumi kedua-dua data kinematik dan kinetik pada lumbopelvic dan anggota bawah badan yang dikaitkan dengan kaki mungkin diperlukan untuk mewajarkan strategi pencegahan dan pengurusan di kalangan orang dewasa dengan sakit belakang.*

Kata kunci: Tekanan; daya maksimum; permukaan sentuhan plantar; sakit belakang; beban

INTRODUCTION

Manual material handling activities such as lifting, carrying, lowering, pushing and pulling are associated with low back pain (LBP) (Derek & Peter 2007; Jozef 2012). There are changes in spinal loads during lifting tasks and these biomechanicalchanges affect vertebral structures of the lumbar spine, especially in adults with LBP (Yang et al. 2002; Martimo et al. 2010). An individual exhibits different motor patterns of the trunk muscles to provide trunk stability and it depends on the weight ofobjects lifted (Oliveira & Gonçalves, 2009). In addition, any sudden lifting of unexpected loads increases the risk of LBP (Heiss et al. 2002).

Changes ofplantar pressure, force and contact area during lifting loads have been reported previously (Pau et al. 2011; Hong & Li 2004; Birrell et al. 2007). In astudy on the effect of military load carriage, it was found thatthere was an increase in ground reaction force with incremental increase of 8 kg of load (Birrell et al. 2007). An increase in plantar pressure and contact area was also demonstrated when backpack loads increased up to 30% (Pau et al. 2011). Moreover, an increase in peak force was reported when loads carried was 15% of body weight (Hong & Li 2004). Changes on the plantar pressure, force and contact area with loads in backpacks, on the head, lifting military equipment and using both hands have been extensively reported (Birrell et al. 2007; Hong & Li 2004; Lloyd et al. 2010). However, information on biomechanics of body structures when lifting loads using one hand is limited.

Lifting loads using single hand is a common daily task. Greater forces werereported on the musculoskeletal system as a result of increased lateral bending of the trunk (Demura & Uchiyama 2007). Individuals with LBP are also found to have increased trunk lateral bending when lifting loads compared to individuals without LBP (Childs et al. 2003). In addition, lifting loadsis one of the task-related risk factors to altered gait patterns (Qu & Yeo 2011).Changes in gait patterns when lifting weights using one hand was deduced to be caused by the increased stresses on the loaded lower limb (Matsuo et al. 2008). More information regarding plantar pressure, force and contact area when lifting loads using one hand is empirical in considering best strategies for lifting, more so for individuals with LBP.

The purpose of our present study was to investigate the changes at the plantar pressure (PP), maximum force (MF) and contact area (CA) during incremental weight carrying (no load, 5 kg, 7.5 kg and 10 kg) using one hand between adults with and without LBP during standing and walking.

EXPERIMENTAL METHODS

In this experimental study with repeated-measures design, participants were recruited through purposive sampling. All the participants provided written informed consent prior to data collection. Ethical approval was obtained from Medical and Research Ethics Committee of Universiti Kebangsaan Malaysia.

PARTICIPANTS

Forty volunteers aged between 30 and 55 years participated in the study. The participants were 20 adults with LBP and 20 matched (age, weight, height, gender and BMI) individuals without LBP. Adults with LBP that presented with chronic non-specific LBP for more than 3 months and were able to walk without any aids were selected. Adults with LBP were recruited from the orthopedic clinic of the university hospital. They were excluded if they had history of acute LBP with duration of less than 6 weeks. Participants were excluded if they were pregnant, had any history of traumatic and neuromuscular problems that required hospitalization over past six months, low back surgery, pain radiating below the gluteal fold, surgical interventions to their lower limbs and lower limb pain due to degeneration or arthritic diseases. Adults with LBP who scored greater than seven in the visual analogue scale (VAS) were excluded as a higher score indicate more pain resulting in possible functional limitations.

MEASUREMENTS

Tekscan Mat Scan Pressure Assessment Systems, Sensor Matscan Version 6.3 (TekScanInc, South Boston, USA) was used to measure the biomechanical changes observed in PP (kPa), MF (% of body weight, %BW) and CA (cm^2). The Matscan system comes with a floor mat embedded with sensors that are made up of 2,000 individual pressure-sensing locations which detects the participants PP, MF and CA precisely. Data from the Matscan system software can be used with various Microsoft systems. Calibration was performed for each mat individually and for all participants before recording participants' data.

MEASUREMENT PROCEDURE

The measurement protocol for the study procedure during standing and walking was based on an established protocol where thereliability of the procedure was reported to be excellent with ICCs ranged from 0.95 to 0.98 (Deepashini et al. 2014a). After a familiarization session, PP, MF and CA were recorded with participant in standing position and during walkingon a 8 m walkway utilizing the two step protocol using their usual speed without foot wearon the Matscan platform with no load, followed by carryinga standardized bag filled with sand weighing 5 kg, 7.5 kg and 10 kg using the right hand with arm beside the body. Three data sets were recorded for each trial with a10-minute rest between each tests. The mean of three measurements was found to be more accurate for plantar pressure, force and contact areameasurements (Deepashini et al. 2014b). All the tests and data recordings were carried out by the main researcher.

DATA ANALYSIS

Statistical analysis was performed using the SPSS 20.0 for Windows (SPSS Inc, Chicago, III). Forty participants with 20 in each group was recruited based on the calculation using G power software (downloaded from http://www.psycho.uni-duesseldorf.de/abteilungen/aap/gpower3/) withpower of 0.80 and effect size of 0.60. A p-value of less than 0.05 was considered statistically significant. A two-way mixed analysis of variance (group × load) (was conducted to measure the PP, MF and CA among adults with and without NSLB Pduring an incremental load (no load, 5 kg, 7.5 kg and 10 kg) in standing and walking. The effect size was measured using the partial Eta square ($\eta^2 p$) where 0.01, 0.06 and 0.14 were considered small, medium and large effect sizes, respectively (Cohen 1988).

RESULTS

DEMOGRAPHICS DETAILS

A total of 40 adults with and without LBP (mean ± SD age 47.83 ± 15.59, height 163.07 ± 5.98, weight 63.68 ± 8.71 and BMI 23.94 ± 2.97) were involved in this study. The demographic details of adults with LBP (n = 20) and without LBP (n = 20) is shown in Table 1. Table 2 shows the plantar pressure, maximum force and contact area in both the feet while carrying different loads in standing and walking. Figure 1 demonstrates the influence of different loads on PP, MF and CA among adults with and without LBP in walking.

TABLE 1. Demographics of adults with LBP (n = 20) and adults without LBP (n = 20)

	Adults with LBP	Adults without LBP	p value
Age/yr	52.10 ± 13.88	43.55 ± 14.57	0.07
Weight/kg	64.76 ± 8.77	62.59 ± 8.73	0.44
Height/cm	163.45 ± 6.63	162.68 ± 5.40	0.69
BMI/kg/m^2	24.22 ± 2.84	23.66 ± 3.13	0.56
Pain intensity (VAS score)	1.50 ± 1.62	–	–
Gender ratio (Male: Female)	10:10	10:10	–

EFFECTS OF PLANTAR PRESSURE, MAXIMUM FORCE AND CONTACT AREA WHILE STANDING

There was no main effect between group on the PP, MF and CA. However, there was a significant main effect between the loads on the PP ($p < 0.05$, effect size = 0.49), MF ($p < 0.05$, effect size = 0.74) and CA ($p < 0.05$, effect size = 0.48) with large effect size in the right lower limb. On the left lower limb, a significant main effect between the loads was observed on the PP ($p < 0.05$, effect size = 0.17) and MF ($p < 0.05$, effect size = 0.23) with large effect size. There was no interaction effect between the loads and groups on the PP, MF and CA in the right and left lower limbs. Table 3 presents the F-ratios, p values and effect size for main effects of group and loads, and interaction effects of group × loads of each dependent variable (PP, MF and CA) in standing tests.

EFFECTS OF PLANTAR PRESSURE, MAXIMUM FORCE AND CONTACT AREA WHILE WALKING

There was no main effect between group on the PP, MF and CA. A significant main effect was observed between the loads on the PP ($p < 0.05$, effect size = 0.28)and MF ($p < 0.05$, effect size = 0.40) with large effect size in the right lower limb. On left lower limb, a significant main effect was observed between the on the PP ($p < 0.05$, effect size = 0.20), MF ($p < 0.05$, effect size = 0.25) and CA ($p < 0.05$, effect size = 0.28) with large effect size. There was no interaction between the loads and groups on the PP, MF and CA within the right lower limb. On the left lower limb, results showed a significant interaction between the loads and groups on the PP ($p < 0.05$, effect size = 0.02), MF ($p < 0.05$, effect size = 0.07) and CA ($p < 0.05$, effect size = 0.07) with medium effect size. The F- ratios, p values and effect size for main effects of group and loads, and interaction effects of group × loads of each dependent variable (PP, MF and CA) in walking tests as shown in Table 3.

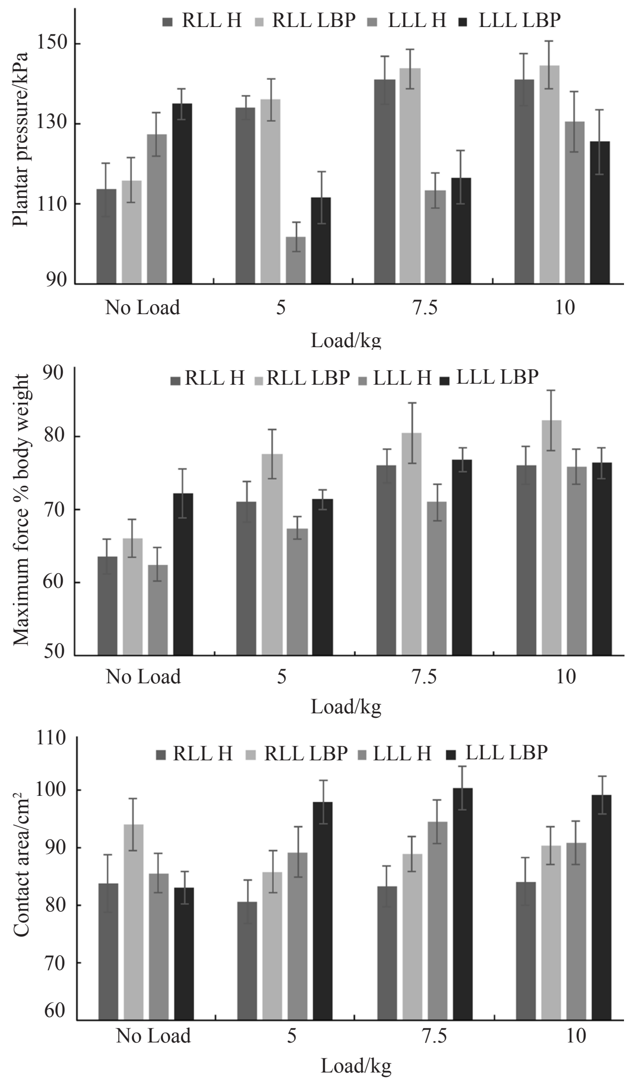

FIGURE 1. Influence of different loads on plantar pressure, maximum force and contact area among adults with and without LBP in walking
[Mean (Standard deviation)]. RLL: Right lower limb, LLL: Left lower limb, H: Adults without LBP, LBP: Adults with LBP

TABLE 2. The plantar pressure, maximum force and contact area in both the feet while carrying different loads in standing and walking

Standing	Right lower limb	Left lower limb
Plantar pressure/kPa		
No load	117.23 ± 38.14	123.04 ± 34.46
5 kg	168.20 ± 61.27	155.18 ± 53.10
7.5 kg	189.04 ± 64.07	142.95 ± 56.42
10 kg	190.09 ± 62.35	135.76 ± 41.90
Maximum force/%BW		
No load	56.29 ± 13.45	58.96 ± 9.85
5 kg	80.01 ± 14.24	72.13 ± 17.10
7.5 kg	94.98 ± 17.38	66.22 ± 16.33
10 kg	98.79 ± 18.17	64.81 ± 15.27
Contact area/cm^2		
No load	77.13 ± 18.13	76.45 ± 13.86
5 kg	82.09 ± 17.72	76.46 ± 12.84
7.5 kg	87.71 ± 16.14	75.80 ± 13.83
10 kg	89.06 ± 15.88	76.38 ± 14.90
Walking		
Plantar pressure/kPa		
No load	114.87 ± 27.30	131.29 ± 21.59
5 kg	135.18 ± 18.76	106.79 ± 23.58
7.5 kg	142.44 ± 24.33	115.01 ± 25.06
10 kg	142.93 ± 27.52	128.11 ± 34.58
Maximum force/%BW		
No load	64.82 ± 10.81	67.39 ± 13.62
5 kg	74.33 ± 13.85	69.44 ± 6.70
7.5 kg	78.22 ± 14.91	73.91 ± 9.72
10 kg	79.15 ± 15.65	76.18 ± 9.88
Contact area/cm^2		
No load	88.88 ± 21.53	84.26 ± 13.89
5 kg	83.15 ± 16.32	93.51 ± 18.87
7.5 kg	86.09 ± 14.97	97.42 ± 16.77
10 kg	87.23 ± 16.74	94.99 ± 16.05

TABLE 3. *F*-Ratios, *p* values and effect size for main effects of group and loads, and interaction effect of group × loads of each dependent variable in standing and walking

Variable*		Main effect of group			Main effect of loads			Interaction of group × loads		
		F (1,38)	p	$\eta^2 p$	F (3,114)	p	$\eta^2 p$	F(3,114)	p	$\eta^2 p$
Standing	PP (R)	0.12	0.74	0.01	37.62	< 0.05	0.49	0.19	0.89	0.01
	MF (R)	2.01	0.17	0.05	110.14	< 0.05	0.74	0.39	0.76	0.01
	CA (R)	1.38	0.25	0.04	35.16	< 0.05	0.48	0.22	0.88	0.01
	PP (L)	1.03	0.32	0.03	7.88	< 0.05	0.17	0.84	0.47	0.02
	MF (L)	0.19	0.67	0.01	11.00	< 0.05	0.23	0.29	0.83	0.01
	CA (L)	1.46	0.24	0.04	0.11	0.96	0.01	1.57	0.20	0.04
Walking	PP (R)	0.27	0.61	0.01	14.39	< 0.05	0.28	0.01	0.99	0.01
	MF (R)	1.73	0.19	0.04	25.65	< 0.05	0.40	0.53	0.66	0.01
	CA (R)	2.04	0.16	0.05	2.31	0.08	0.06	0.52	0.67	0.01
	PP (L)	0.50	0.48	0.01	9.66	< 0.05	0.20	0.79	< 0.05	0.02
	MF (L)	4.14	0.06	0.10	12.59	< 0.05	0.25	2.97	< 0.05	0.07
	CA (L)	1.30	0.26	0.03	14.94	< 0.05	0.28	3.02	< 0.05	0.07

* PP = plantar pressure, MF = maximum force, CA = contact area, R = right lower limb, L = left lower limb

DISCUSSION

The current study investigated the changes at the plantar pressure, maximum force and contact areaduring carrying incremental weights (no load, 5 kg, 7.5 kg and 10 kg) using one hand between adults with and without LBP. The results suggest that plantar pressure, force and contact area were similar in adults both with and without LBP when standing and walking. However, there were changes in the left plantar pressure, force and contact area while carrying incremental loads during walking. Plantar pressure, force and contact area changed while carrying incremental loads during walking but remained the same during standing.

There were no differences in the pattern of plantar pressure, force and contact areabetween adults with and without LBP. Thiscan possibly be due to similarity in the standing and walking patternamong adults with and without LBP that resulted in no differences in the plantar pressure, force and contact area.

There was also no significant interaction between the loads and groups in adults with and without LBP during standing and could be due to the standardized load lifting technique in this study. The results of our study are supported in a previous study, where lifting a 12 kg load during flexion-extension of the trunk did not discriminate individuals with and without LBP (Lariviere et al. 2000).

Similar patterns of plantar pressure, force and contact areabetween adults with and without LBP may also be due to the absence of radiating pain and mild nature of pain in the participants with LBP in the present study. There is a possibility that participants with LBP would have ignored mild pain and performed the test with no difference compared to individuals without LBP. According to the theory of avoidance-endurance model (AEM), adults with LBP have a tendency to shut off from pain experience and continue with their activity (Zahraee et al. 2014; van Weering et al. 2007; Griffin et al. 2011). There is also limited evidence that adults with and without LBP differ in their activity levels (van Weering et al. 2007; Griffin et al. 2011).

Standing and walking patterns can influence plantar pressure, force and contact areaand one reason that might change these patterns may be limitation of motion in the lower limbs. Restricted hip motion due to persistent nerve root irritation is common in adults with LBP (Lariviere et al. 2000).

Moreover, individuals with LBP who experience radiating pain werenoted to be more disabled compared to adults with LBP but without radiating pain (Selim et al. 1998). It is noteworthy that in our present study we did not include adults with LBP who had radiating pain in view of worsening their symptoms during the tests as it involves carrying loads. Thus, similar patterns of plantar pressure, force and contact areabetween the two groupsare possible.

A significant increase of CA in right foot during standing was demonstrated when with incremental loads. The right foot CA increase can be explained by the fact that the center of mass shifting to the right in response to the added loads and carrying using the right hand. This shifting to the right leads to increase in right plantar ground contact area. However, during walking, CA of the right foot showed no significant differences with a significant increase in the left foot. This may be an adaptive strategy, possibly in response to maintain balance while walking. There are changes in the body posture when carrying loads, mainly to restore the initial position of its center of mass to maintain support and balance (Negrini 2007; Brackley et al. 2009).

A significant interaction between the loads and groups on the PP ($p < 0.05$), MF ($p < 0.05$) and CA ($p < 0.05$) of the left lower limb was demonstrated in the study. Generally, one lower limb is used to support the body for 80% of the time during walking (Stolwijk et al. 2010).

Hence, we deduce that there were some adjustments in the walking pattern where the left lower limb was used mainly to maintain balance and stability as the loads were carried using the right hand during walking. Adjustments during walking enables lower limb muscles to function normally even when extra load were carried (Kim et al. 2014).

There are a few limitations in the present study that should be considered in generalizing the results. Firstly, the current study was laboratory based with data collection lasting for about an hour. In the daily activities, individuals may be standing and walking while carrying loads for longer periods.

Thus, the current study result may not reflect the plantar pressure, force and contact areachanges when loads were carried for a longer period during standing and walking. Secondly, muscle fatigue due to prolonged load carryingas in daily activities can influence the distribution of force and pressure through the lower limbs. However, in our present study we minimized the potential impact of muscle fatigue by providing sufficient rest between each carrying tasks during standing and walking.

We suggest future studies on plantar pressure, force and contact area during lifting task to be performed mimicking activities of daily living. Plantar pressure, force and contact areamay differ with lifting compared to carrying task.

CONCLUSION

In summary, the results of the present study indicatedsimilar patterns of plantar pressure, force and contact areain adults with and without LBP. No changes in plantar pressure, force and contact areawhile carrying incremental loads were observed during standing. However, an alteration in plantar pressure, force and contact areaon the non-loaded site was observed while carrying incremental loads during walking.

The results of our study add to the knowledge regarding changes in plantar pressure, force and contact area when carrying incremental loads in standing and walking among adults with and without LBP using one hand which is a common daily functional routine.The results of our study suggest that stresses imparted to the foot changes during dynamic postures and this may be a compensatory mechanism. Plantar pressure, force and contact area were similar in adults both with and without LBP when standing and walking. Further biomechanical information that includes both kinematic and kinetic data in lumbopelvic and lower limbs in relation to the foot may be required to justify for prevention and management strategies.

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