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Effect of surface inclination and gluteus maximus activation on lumbar lordosis and footpronation in individuals with low back pain with extension pattern: a preliminary study

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Lumbar hyperlordosis and foot overpronation are associated with low back pain with extension pattern. This study examined if standing and walking on inclined surface or gluteus maximus activation alleviates the extent of lumbar lordosis and foot pronation amongst individuals with LBP who were classified with extension pattern. Eighteen adults with foot overpronation (LBP group, $n = 9$ and non-LBP group, $n = 9$) participated in this cross-sectional and case-control comparison study. Lumbar lordotic angle and rearfoot angle were measured using surface tomography, during standing and walking on treadmill at inclinations of 0°, 6° and 9°, and voluntary gluteus maximus activation at 20%, 40% and 60% of maximal contraction in standing at 0° inclination. The lumbar lordosis angle and rearfoot angle were compared within-group and between two groups across the listed trials in standing and walking. Results indicated no significant change in lumbar lordosis or rearfoot angle in LBP group when standing or walking on 6°or 9°inclined surface ($p > 0.05$). However, voluntary gluteus maximus activation in standing at the level of 20%, 40% and 60% of maximal effort reduced lumbar lordotic angle ($p < 0.05$) but not rearfoot angle ($p > 0.05$) in LBP group. Our findings provide a novel approach to address the hyperlordosis in LBP group with extension pattern, for which voluntary gluteus maximus activation of ≥ 20% of maximal effort could effectively reduce the extent of the lumbar lordosis in level-ground standing in the LBP group. Such modified lumbar posture may alleviate the compressive loading on the spine associated with static upright standing at our daily activities. Increased gluteus maximus activation found during inclined walking may be beneficial to those with LBP and extension pattern.

Keywords Lordosis, Foot pronation, Low back pain, Gluteus Maximus, Inclined surface

Low back pain (LBP) is the leading cause of global disability[1]. Clinically, LBP with mechanical origin can be classified into subtypes based on their movement-based impairments for more efficient management. Lumbar extension pattern is one of the most common types of LBP, in which one's symptoms are provoked by positions or movements towards the lumbar extension, including standing and walking[2]. It had been reported that LBP patients walked differently in terms of walking speed, joint kinematics, and kinetics[3,4]. Typical posture with the increased lumbar hyperlordosis had been revealed in individuals with extension pattern LBP[5]. In addition to some risk factors that have been reported to be related to lumbar hyperlordosis e.g., imbalance of the truncal muscle strength[6], family history[7] and extent of abdominal adiposity[8], the lower limbs biomechanics was also a contributing factor to the lumbar hyperlordosis. This is because foot overpronation may contribute to excessive tibial and femoral internal rotation, resulting in excessive anterior pelvic tilt and subsequent lumbar hyperlordosis or vice versa[9]. Meanwhile, lateral heel flare of footwear[10] and obesity[11] have been reported as

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the risk factors for foot pronation. The theory of the biomechanical inter-dependency between the lumbar curvature and foot alignment is further supported by a strong correlation found between lumbar lordosis and foot overpronation among healthy individuals[9,12,13]. However, limited research evidence is available to affirm whether such correlation is consistently displayed in those with LBP. Dharmayat et al.,[14] had provided emerging evidence to substantiate the positive correlation between the extent of the lumbar lordosis (which was quantified by conversion of the measurement of the curve ruler positioned over the lumbar region) and the foot posture (which was categorized as ordinal Chippaux index: neutral/partial pronated or supinated/pronated or supinated based on the area of the footprints) of individuals with LBP.

Apart from conventional passive interventions including foot orthotics and taping, gluteus maximus (GMax) strengthening exercise was proven to be effective in correcting foot overpronation[15–17]. GMax is the primary hip extensor and external rotator[18]. Its contraction counteracts the femoral and tibial internal rotation, which can potentially correct the altered lower limb mechanics secondary to foot overpronation[19]. Moreover, GMax is the largest muscle connecting the lower limbs with the lumbar spine through thoracolumbar fascia[20]. Its activation essentially contributes to lumbopelvic dynamic stability during functional movements including locomotion and lifting[21]. Individuals with LBP showed to have impaired motor control during walking and significantly decreased GMax activity during functional activities[3,22–26]. Koh et al. found that voluntary GMax activation at maximal effect monitored by real-time electromyography (EMG) reduced the lumbar lordosis and foot pronation in standing position in healthy individuals[27]. However, such effects on lumbar and foot alignment in standing as well as in walking in individuals with LBP are yet to be investigated.

This study aimed (1) to examine the correlation between lumbar lordosis and foot pronation in standing and walking on level ground, and (2) to investigate the effect of surface inclination on the extent of the lumbar lordosis and foot pronation in standing and walking, and (3) to investigate the effect of GMax activation on lumbar lordosis and foot pronation in standing on level ground, in adults with or with back pain that were classified with lumbar extension pattern. We hypothesized that there would be a positive correlation between the lumbar lordosis and foot pronation in standing and walking performed on level ground (for Objective 1). In addition, we hypothesized that there would be significant differences in the degree of lumbar lordosis and foot pronation in standing and walking within groups (as the main effect) and condition-and-group interaction found between different conditions of surface inclination (Objective 2) and between different levels of GMAx activation in standing at 0° inclination (Objective 3).

Method

Study design and setting

This cross-sectional and case-control comparison study was conducted between 20 December 2022 and 21 February 2023 at The Hong Kong Polytechnic University. Ethics approval of this study was obtained from the Institutional Review Board of The Hong Kong Polytechnic University (HSEARS20220913001) and all procedures followed the Declaration of Helsinki. Explanation of the study details and written informed consents were obtained from all eligible participants before the experiment commenced.

Participant recruitment and allocation

Participants aged between 18 and 40, presented with a navicular drop of ≥ 10 mm[28], and with or without LBP were recruited through flyers posted in campus. Participants with LBP rated > 2 cm on the Visual Analogue Scale and those who are pain-free were allocated into LBP and non-LBP groups respectively[29]. All potential participants were screened by a registered physiotherapist with 5-year experience in musculoskeletal practice using the criteria listed above. In addition to history taking of their LBP and verification of lumbar extension as their provocative direction for posture adoption and movement execution, clinical features associated with lumbar extension pattern displayed in potential participants, were verified as having positive forward rocking test and prone knee bend test[30]. Additional exclusion criteria that applied to both groups included: history of major trauma or surgery to spine or lower extremity, referred symptoms below buttocks, neurological deficit or nerve root tension signs, leg length discrepancy ≥ 1 cm, inability to walk independently with speed of 2.7 km/h (equivalent to 7.5 m in 10 s) or with an inclination of 9°[31]. Demographics including age, body height, body weight were obtained prior to experimental procedures. A sample size of 8–18 was calculated based on the reported effect size of 0.468 (RFA) and 0.88 (lumbar lordotic angle) with activation of GMax in standing with significance level of 0.0167 and power of 0.95, using G*Power[28].

Instrumentation and measurements

Surface tomography of lumbar spine and foot kinematics

Lumbar lordotic angle (LLA) and rearfoot angle (RFA) were measured by surface tomography method (DIERS Formetric® III 4D, Germany) and a treadmill with the inbuilt force plate respectively, at sampling frequency of 50 Hz. A total of 18 reflective markers were placed at spinous processes of C7, T3, T6, T9, T12, L3, bilateral posterior superior iliac spines, gluteal folds, middle point of the popliteal folds, between two muscle bellies of gastrocnemius, top edge and bottom edge of calcaneus, to enable the reconstruction of the LLA and RFA using the rasterstereography method (Fig. 1). The maximum LLA was measured between the surface tangents of thoracic-lumbar inflection point and lumbar-sacral inflection point[32]. Meanwhile, the RFA was simultaneously measured by the lines joining calf muscle and the top edge of calcaneus, and that joining the top and bottom edge of calcaneus of the respective leg at the static standing conditions and at the mid-stance phase of the gait cycle during walking conditions detailed in the experimental procedures below. The mid-stance phase detection of the corresponding gait cycle during the walking conditions was determined by foot pressure data acquired by the force plate[33]. The positive value of RFA represents the extent of foot pronation while the negative value represents the extent of foot supination[27]. In walking conditions, the maximal eversion angle of rearfoot was

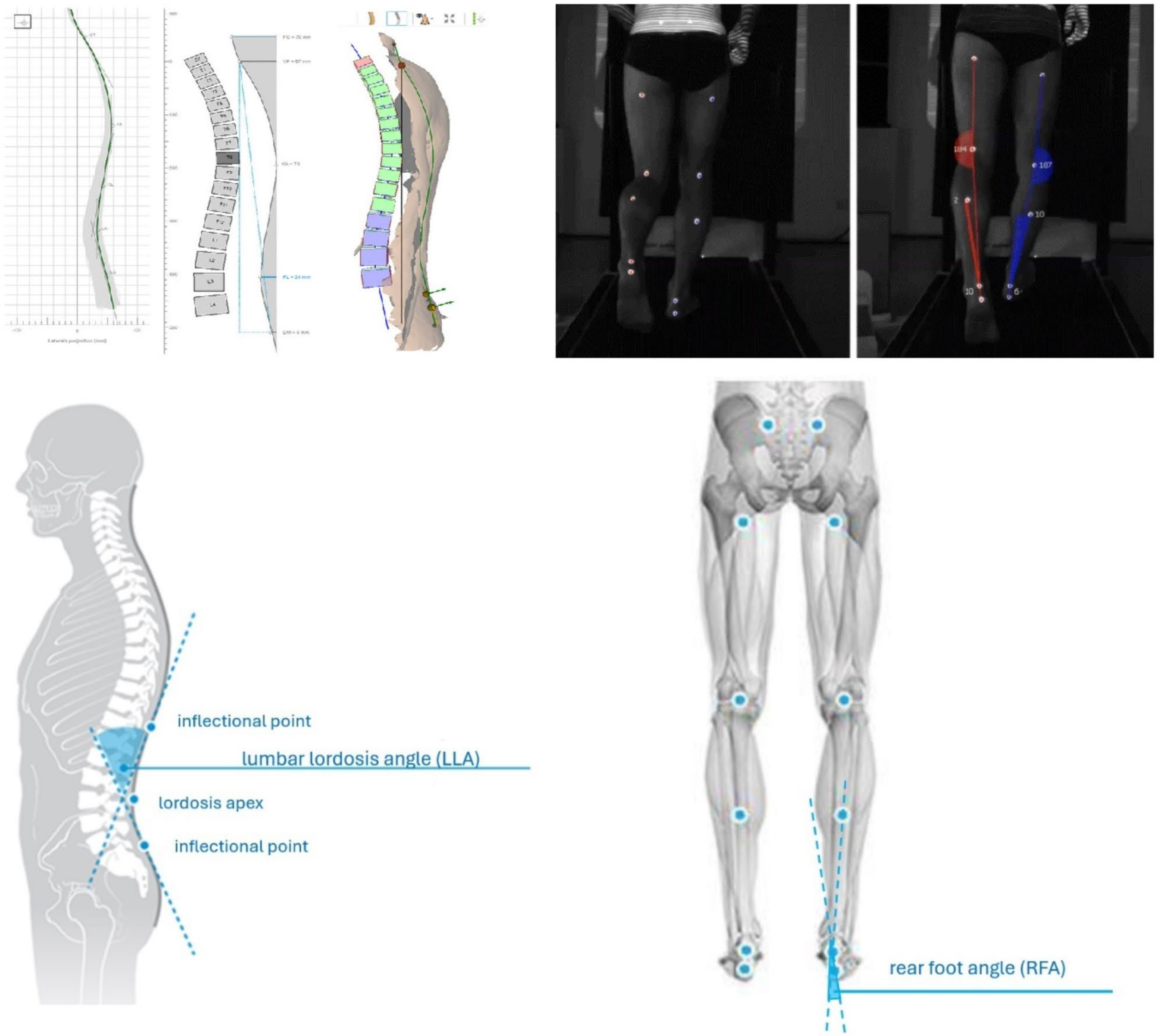

Fig. 1. Measurements of the lumbar lordotic angle and rear foot angle using surface topography.

obtained from the largest positive value of RFA within the 6-second recording. Although excellent test-retest reliability (ICC = 0.90–0.94) of the angle measurements using the same surface tomography system has been reported[34], the values of LLA and RFA obtained from the three trials of each testing condition included in this study were assessed for their measurement reliability (refers to the details in Experimental procedures below).

Electromyographic amplitude of gluteus maximus

Surface electromyography (EMG) of the bilateral GMax was recorded at the sampling frequency of 2000 Hz (Ultium, Noraxon Inc., U.S.A.). Electrodes were placed in the middle of the muscle clearly below the level of the trochanter, 1–2 inches above the gluteal fold, oriented laterally at approximately a 25° angle of vertical axis to follow the muscle fibres orientation, after the standardized skin preparation procedures[35]. Maximal voluntary contraction (MVC) value of the GMax obtained from the resisted hip extension performed in supported prone lying position with maximal effort was used to normalize its activation level recorded during tasks expressed in percentage of MVC (%MVC)[36]. To enable the studying of the effect of active GMax contraction at different levels on lumbar spine and foot kinematics, three levels of activation (20%, 40% and 60% of MVC) were investigated in the present procedures.

Experimental procedures

Figure 2 shows the details of the experimental procedures. Participants were required to complete a series of standing and walking conditions on the treadmill at 0° inclination first, followed by 6° and 9° in randomized order (Conditions 1–3), and finally the activation of GMax in standing at 0° inclination at 20%, 40% and 60% of

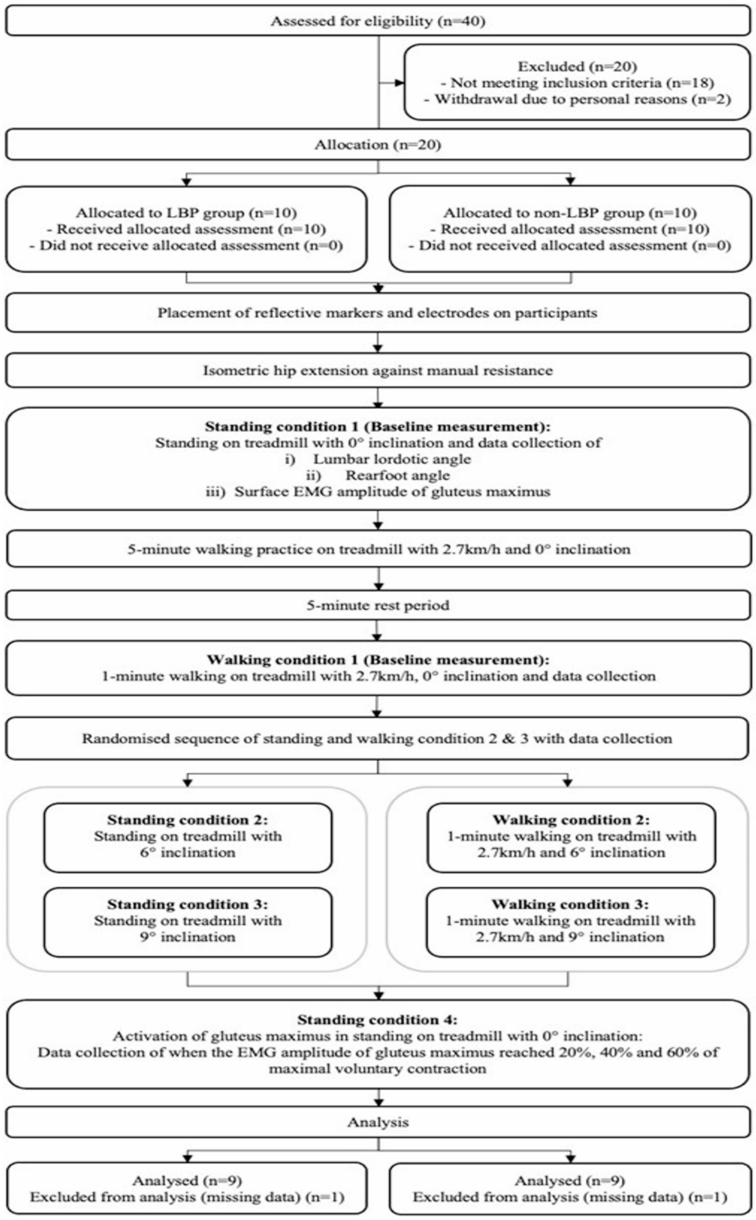

Fig. 2. Flowchart of the study.

MVC levels (Condition 4–6). Real-time measurements of the LLA, RFA, and GMax activity were recorded in all three trials for each specified condition, with 1-minute rest between trials.

After the testing of conditions in standing, participants practiced the treadmill walking for 5 min to familiarize themselves with the setup followed by a 5-minute rest period, before the actual walking conditions commenced. Walking speed at 2.7 km/hr and inclination at maximum of 9° inclination were adopted in this study for the effective activation of gluteus maximus previously reported in cohort of asymptomatic participants[31,37]. Measurement was conducted during the final 6 s of each 1-minute trial while the same procedure was repeated for walking conditions 2 (6° inclination) and 3 (9° inclination).

To achieve the valid experimental setup for testing the effect of GMax activation at the various levels on the lumbar spine and foot kinematics, in standing at 0° inclination, participants were trained to actively recruit their GMax using the standardized verbal instructions, "to squeeze the muscles of your buttock and open your anterior pelvis by rolling your pelvis outwards gradually". The LLA and RFA were measured when the normalized GMax amplitudes achieved steadily at 20%, 40% and 60% of MVC verified by the real-time EMG activity monitoring for Conditions 4–6 respectively.

Statistical analysis

Statistical analyses were performed using SPSS version 29. Test-retest reliability of LLA and RFA measurements between three trials for each task condition was analyzed with ICC (3,3), using a 2-way mixed model and absolute

Variables	Groups		*p*-value
	LBP group (*n* = 9)	Non-LBP group (*n* = 9)	
Age (year)	25.78 ± 4.71	25.78 ± 4.99	1.00
Gender* (female/male)	6/3	3/6	0.18
Height (m)	1.63 ± 0.07	1.68 ± 0.08	0.19
Weight (kg)	61.78 ± 19.04	67.00 ± 15.71	0.54
Body mass index (kg/m^2)	22.93 ± 5.62	23.47 ± 3.77	0.82
Pain intensity (VAS in cm)	3.33 ± 1.01	0.00 ± 0.00	< 0.001
Left navicular drop test (mm)	12.1 ± 0.34	13.7 ± 0.19	0.33
Right navicular drop test (mm)	12.3 ± 0.29	12.8 ± 0.29	0.77

Table 1. Baseline characteristics of the participants. All values except gender are expressed in mean ± standard deviation. VAS: Visual Analogue Scale. *Analyzed by Chi-Square.

Tasks	Inclination	Measurement	ICC
Standing	0°	LLA	0.96
		RFA_{Left}	0.96
		RFA_{Right}	0.94
	6°	LLA	0.97
		RFA_{Left}	0.95
		RFA_{Right}	0.97
	9°	LLA	0.97
		RFA_{Left}	0.96
		RFA_{Right}	0.98
Walking	0°	LLA	0.90
		$RFA_{Left-ME}$	0.87
		$RFA_{Right-ME}$	0.98
	6°	LLA	0.97
		$RFA\text{-}ME_{Left}$	0.80
		$RFA\text{-}ME_{Right}$	0.97
	9°	LLA	0.93
		$RFA\text{-}ME_{Left}$	0.77
		$RFA\text{-}ME_{Right}$	0.94

Table 2. Summary of test-retest reliability of lumbar spine and foot kinematic measurements. Analysis of ICC was based on a two-way mixed-effects model with absolute agreement. LLA: lumbar lordotic angle; RFA: rearfoot angle; RFA-ME: rearfoot angle measured at maximal eversion of rearfoot.

agreement. Correlation between LLA and RFA during standing and walking with 0° inclination was analyzed using Pearson correlation analysis. The between-group and between-task, and group-and-condition interaction effect were analyzed with two-way repeated measures ANOVA with contrast analysis, or if applicable, non-parametric alternatives.

Results

Participants

A total of forty individuals were contacted and informed of this study. Eighteen individuals were excluded since they did not fulfil the inclusion criteria while two withdrew from the study due to personal reasons. Twenty participants who fulfilled the selection criteria and provided informed consent were included in the study. Due to the missing data, only eighteen participants were analyzed. Their baseline characteristics are shown in Table 1.

Reliability of measurement and correlation between lumbar lordosis and foot alignment

Table 2 shows the summary of the test-retest reliability of kinematic measurements between the three trials of each testing condition, and the values of the ICC indicate an excellent reliability for measurement of the LLA (ICCs range 0.90–0.97) and good to excellent reliability for measurement of the RFA (ICCs range 0.77–0.98). No significant correlations were found between LLA and bilateral RFA during standing and walking on 0° inclination under examination, in both groups (Table 3).

Tasks	Standing		Walking	
LBP group				
	Left RFA ($n=6$)*	Right RFA ($n=4$)*	Left RFA-ME ($n=6$)*	Right RFA-ME ($n=4$)*
LLA ($n=9$)	0.61 (0.20)	0.29 (0.71)	−0.11 (0.84)	−0.59 (0.41)
Non-LBP group				
	Left RFA ($n=7$)*	Right RFA ($n=9$)	Left RFA-ME ($n=7$)*	Right RFA-ME ($n=9$)
LLA ($n=9$)	−0.18 (0.70)	0.43 (0.24)	−0.33 (0.47)	0.07 (0.86)

Table 3. Correlation between lumbar lordosis and foot pronation expressed in correlation coefficients (p value) during standing and walking at 0° inclination. LLA: lumbar lordotic angle; RFA: rearfoot angle; RFA-ME: rearfoot angle measured at maximal eversion of rearfoot. *Examined legs with navicular drop greater than 10 mm.

Effect of surface inclination on LLA, RFA, and GMax activation in standing

For LLA, a significant within-group difference was only found in non-LBP group between 6° and 9° inclination standing ($p=0.05$, $\eta2=0.41$), with LLA reduced from 31.37° on 6° inclination to 30.11° on 9° inclination (Fig. 3a). No significant between-group difference and group-and-condition interaction were found on different degrees of inclination($p=0.09–0.97$, $\eta2=0.001–0.32$) (Fig. 3a). For bilateral RFAs, no significant within-group differences, between-group differences and group-and-condition interaction were found on different degrees of inclination ($p=0.14$-1.00, $\eta2=0.001–0.57$) (Fig. 3d and g).

For bilateral GMax activation, significant within-group differences were found between 0° and 6° inclination ($p=0.04$, $\eta2=0.44$), 0° and 9° inclination ($p=0.02$, $\eta2=0.52$) for left GMax in LBP group (Fig. 2j) for which the EMG amplitudes of the bilateral hip extensors were greater when standing on inclined surfaces compared to that on 0° inclination. In non-LBP group, left GMax activity on 9° inclination (2.59% MVC) was significantly greater than that on 0° inclination (2.09% MVC) ($p=0.02$, $\eta2=0.49$) (Fig. 2j). Besides, a significant difference in EMG amplitude of right GMax was found between 6° inclination (1.28% MVC) and 9° inclination (1.47% MVC) ($p=0.01$, $\eta2=0.60$) (Fig. 3l). No between-group differences and group-and-condition interaction were found in both groups (Fig. 3j and l).

Effect of surface inclination on LLA, RFA in maximal eversion of rearfoot, and GMax activation during walking

For LLA, no significant within-group differences or group-and-condition interaction were found in both groups on different degrees of inclination ($p=0.20–0.99$, $\eta2=0.001$-0.20). However, a between-group difference was observed on 0° inclination ($p=0.03$, $d=8.92$) (Fig. 3b).

For bilateral RFAs in maximal eversion, no significant within-group differences were found in both groups on different degrees of inclination, except the significantly reduced in left RFA in maximal eversion in non-LBP group found between 0° and 6° inclination ($p=0.04$, $\eta2=0.55$) (Fig. 3e). No significant between-group differences and group-and-condition interaction were found in both groups on different degrees of inclination ($p=0.11–0.98$, $\eta2=0.001–0.46$) (Fig. 3e and h).

For left GMax activation, both groups demonstrated a significant increase in EMG amplitude between 0° and 9° inclination (LBP: $p=0.02$, $\eta2=0.53$; non-LBP: $p<0.01$, $\eta2=0.58$), 6° and 9° inclination (LBP: $p=0.01$, $\eta2=0.64$; non-LBP: $p=0.01$, $\eta2=0.63$), respectively (Fig. 3k). For right GMax activation, both groups showed significantly greater GMax activities with the increase of inclination (LBP: $p<0.001$, $\eta2=0.76$; non-LBP: $p<0.001$, $\eta2=0.79$) (Fig. 3m). No significant between-group differences and group-and-condition interaction were found in both groups on different degrees of inclination (Fig. 3k and m).

Effect of voluntary GMax activation on LLA and RFA in standing on 0° inclination

There were significant reductions in LLA with 20%, 40% and 60% MVC of GMax when compared to baseline in LBP group ($p<0.001$, $\eta2=0.49$) (Fig. 3c). Besides, the reduction in LLA with 40% MVC of GMax was significantly greater than that with 20% MVC ($p=0.03$, $\eta2=0.45$). In non-LBP group, the only significant decrease in LLA was found in 60% MVC of GMax when compared to 20% MVC ($p=0.02$, $\eta2=0.54$) (Fig. 3c). No significant between-group differences and group-and-condition interaction were found in both groups with different extents of voluntary GMax activation (Fig. 3c).

For bilateral RFAs, no significant within-group differences, between-group differences, and group-and-condition interaction) were found for the extent of voluntary GMax activation (Fig. 3f and i).

Discussion

Present findings showed that LBP group had a significantly greater LLA than non-LBP group in walking at 0° inclination, however, no significant correlation was found between lumbar lordosis and foot pronation in both groups. Neither the lumbar lordosis nor foot pronation was altered significantly in standing and walking on inclined surface in both groups. However, a significantly greater GMax activation in inclined walking was found when compared to 0° inclination in both groups. Voluntary GMax activation at effort 20%, 40% and 60% of MVC in flat-surface standing reduced the extent of the lumbar lordosis but not the foot pronation in LBP group.

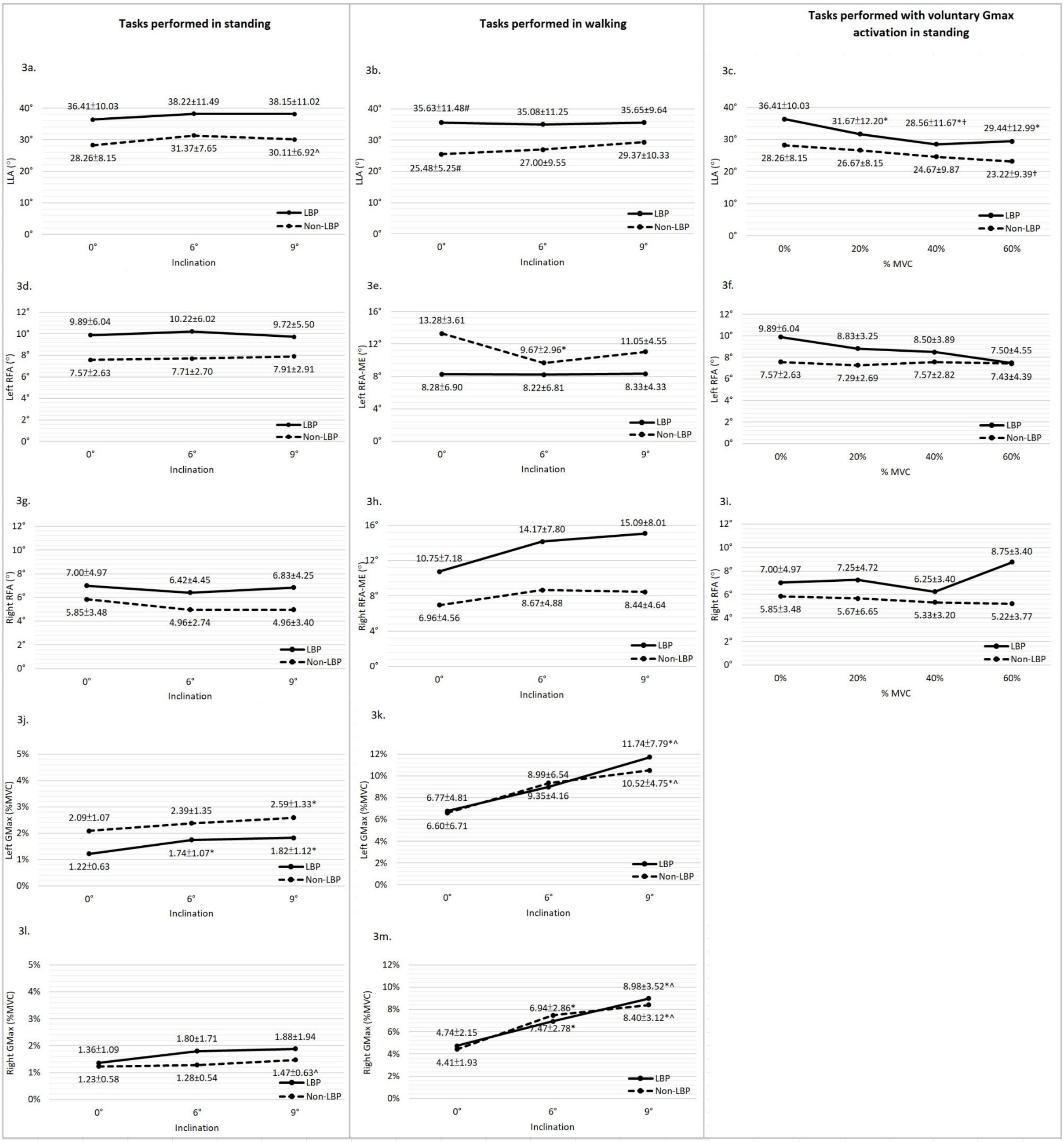

Fig. 3. Changes in lumbar lordotic angles (**a**–**c**) and bilateral rearfoot angles (**d**–**i**) in standing and walking with different degrees of surface inclination and voluntary GMax activation, and changes in bilateral GMax activation in standing (**j**–**k**) and walking (**L**–**m**) with different degrees of surface inclination. LLA: lumbar lordotic angle; GMax: gluteus maximus; RFA: rearfoot angle; ME: maximal eversion of rearfoot; MVC: maximal voluntary contraction (*. $p < 0.05$ when compared to baseline; #. $p < 0.05$ in the between-group comparison; †. $p < 0.05$ when compared to 20% MVC; ^. $p < 0.05$ when compared to 6˚ inclination).

LBP group displayed with a larger LLA when compared to the non-LBP group in general which concurs those reported in individuals with LBP extension pattern at baseline[38]. However, a significant difference was only found in walking on a flat surface. The subtle reduction of LLA in all participants observed from standing to ground walking could be explained by the compensatory movements in flexion direction of the lumbar spine during walking[39] which offsets the natural pelvic movement to maintain the upright trunk position and location of the centre of mass[40].

Correlation between lumbar lordosis and Rear foot angle

Although no significant correlations were observed between LLA and RFA during walking and standing on 0° inclination in both groups, high correlation coefficients were revealed in some paired correlation analyses in the LBP group. Only those with navicular drop greater than 10 mm[28] were included in the correlation analysis, and the small sample size might be inadequate to reveal a true significance. It could also be caused by the relatively lower extent of lumbar lordosis and foot pronation amongst our study participants as compared that reported previously (average LLA of 53° and with exaggerated RFA using a 10°-wedge of placed underneath the participants' heels) where significant correlations were found[13,14]. Besides, the degree of freedom of the hip and knee articulations may influence the resultant effect of the foot position in view of the change of the lumbopelvic kinematics[41,42].

Effect of surface inclination and voluntary GMax activation on LLA and RFA

The lack of significant within-group difference in LLA in standing conditions could be explained by the essentially low GMAx activity revealed during quiet standing between 0°, 6° and 9° inclinations (1.22–2.59% of MVC only). With the extent of the anterior pelvic tilting associated with the lumbar lordosis presented in standing for our study participants, it lengthens the GMax which might contribute to the hypoactivity observed in quiet standing[43]. In contrast, voluntary GMax activation at 20%, 40% and 60% MVC was able to effectively reduce the LLA in LBP participants in standing. This suggests GMax activation could potentially be applied to relieve the accumulative compressive load acts on the low back by alleviating the lumbar lordosis for those with extension pattern of LBP[44].

Both LBP and non-LBP groups showed consistent findings in our study with a slight increase in their LLA when standing on inclined surface. Our findings concur with previous studies for the postural alignment of greater lumbar extension with increased anterior pelvic tilt and hip flexion in standing on inclined surface[45,46]. Reduced GMax activity in quiet standing had been identified in individuals with LBP[47]. Such low level of muscle activity (< 2.6% of MVC) in standing on inclined surfaces would unlikely be sufficient to alleviate the extent of lordosis substantially.

The preset treadmill walking speed of 2.7 km/h adopted in this study could contribute to various movement strategies amongst the participants, e.g., adjusting their cadence and stride length. Erector spinae and rectus femoris might be recruited to address the walking pace. Activation of these spinal and knee extensors would counteract the effect of GMax on the pelvic position in the sagittal plane[4,48]. Moreover, a previous study showed that individuals with LBP tended to walk slower with smaller strides[4]. Greater erector spinae activation in this group was also noted during walking[4,49]. Although the automatic increased GMax activation during the walking tasks failed to reduce the real-time LLA in LBP group, its potential to optimize lumbopelvic motor control in long-term is yet to be investigated.

There were no significant changes in RFA found in walking on various degrees of inclinations and voluntary GMax activation. As explained above, this could be due to insufficient GMax activation in the assigned tasks, which might not overcome the counter effects of other muscles. For biomechanic link between the knee and ankle articulation, GMax activation helps overcome the counteracting effects of the ankle evertors and tibial internal rotator muscles, and promotes subtalar inversion. Besides, RFA was shown to be influenced by knee adduction moment[50]. Therefore, the effect of GMax on RFA could not be fully investigated without assessing the contribution of other relevant muscles involved in the lower limb biomechanics.

The maximum inclination in this study was 9° while an inclination of 11.5° adopted in previous work demonstrated significant increase activity in GMax[50] The full potential of activation associated with walking on inclined surfaces at further increment of inclination is yet to be investigated[31]. Besides, the relatively lower extent of lumbar hyperlordosis and foot overpronation in this cohort implies that our findings should only be applied to those with comparable spine and foot alignment. Furthermore, a "top-down approach" initiating from the hip was examined here while a "bottom-up approach" initiating from the foot and ankle should also be considered to comprehend the associated impact on the foot overpronation.

There are several limitations identified in this case-control cross-sectional study for which interpretation and application of the relevant findings should be made with caution. First, instead of a comprehensive motor control test battery, only two clinical tests of extension-bias i.e., forward rocking test and prone knee bend test were used along with individuals' LBP history and provocative posture and movement to identify the clinical features of potential participants with LBP extension subgroup. Second, although mean value of the BMI of the participants indicate that they were not obese at the time of testing, other risk factors related to the angle of lumbar lordosis (e.g., imbalance of the truncal muscle strength, family history) and food pronation (e.g., footwear) were not measured in this study. Finally, the possible confounding effects associated with the uneven distribution of gender in our recruited cohort of participants between the case and control groups, lack of information of the leg dominance, and classification of the severity of the foot overpronation due to the selection of the measurement method adopted in this study might also limit the generalizability of the present findings.

Conclusions

This study shows that voluntary GMax activation of ≥ 20% MVC (40% MVC would be more optimal) but not the surface inclination was able to reduce the lumbar lordosis in individuals with LBP extension pattern in quiet standing. The activity level of GMax during walking on 9° inclination (10.2% MVC) failed to alter the lumbar or RFA of those with or without LBP. Training individuals with extension pattern of LBP by walking on an inclined treadmill can be feasible to promote the motor recruitment and control of the gluteal muscle. Further studies with those with a greater extent of lumbar lordosis and foot pronation and testing at a higher degree of inclination or different walking speed are recommended to investigate the potential in assisting the rehabilitation.

Data availability
All data supporting the results reported in this manuscript has been presented in the tables and figures included with the submission. The dataset is made available in a separable file as the supplementary information.

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Declarations

Competing interests
The authors declare no competing interests.

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