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The changes of lumbar muscle flexion–relaxation response due to laterally slanted ground surfaces

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Lifting tasks performed on uneven ground surfaces are common in outdoor industries. Previous studies have demonstrated that lifting tasks performed on laterally slanted ground surfaces influence lumbar muscle activation and trunk kinematics. In this study, the effect of laterally slanted ground surfaces on the lumbar muscle flexion–relaxation responses was investigated. Fourteen participants performed sagittal plane, trunk flexion–extension tasks on three laterally slanted ground surfaces (0° (flat ground), 15° and 30°), while lumbar muscle activities and trunk kinematics were recorded. Results showed that flexion–relaxation occurred up to 6.2° earlier among ipsilateral lumbar muscles with an increase in laterally slanted ground angle; however, the contralateral side was not affected as much. Our findings suggest that uneven ground alters the lumbar tissue load-sharing mechanism and creates unbalanced lumbar muscle activity, which may increase the risk of low back pain with repeated exposure to lifting on variable surfaces.

Practitioner Summary: Uneven ground surfaces are ubiquitous in agriculture, construction, fishing and other outdoor industries. A better understanding of the effects of laterally slanted ground surfaces on the interaction between passive and active lumbar tissues during lifting tasks could provide valuable knowledge in the design of preventive strategies for low back injuries.

Keywords: low back pain; laterally slanted ground; trunk bending; flexion–relaxation phenomenon

1. Introduction

Low back pain (LBP) is a significant occupational problem with a high incidence rate and high compensation costs. In the USA, back and spine problems ranked as the second most common reason for disability in adults (CDC 2009) with a lifetime prevalence rate of 59%. Among those that have ever experienced LBP, 41% experienced persistent LBP annually (Waxman, Tennant, and Helliwell 2000). Results of a national survey showed that more than 15% of adults have experienced back pain in the 2 weeks prior to the survey (Ricci et al. 2006). According to previous research, LBP is responsible for 12.5% of all working population sick days (Andersson 1999) and has an estimated annual cost close to 20 billion dollars (Stewart et al. 2003). On average, nearly 40% of all LBP cases are work related with even higher ratios found in labour-intensive industries (Punnett et al. 2005). Therefore, the identification of work-related risk factors in the occupational environment holds the key to the prevention of LBP.

Previous studies have demonstrated that uneven ground conditions decrease trunk stability (Lin and Nussbaum 2012), increase the risk of falling (Simeonov et al. 2003) and alter workers' lifting techniques (Wickel and Reiser 2008). In addition, an increase in spinal loading during lifting on anteroposteriorly sloped ground surfaces was also reported (Shin and Mirka 2004). Although flat and balanced ground surfaces are common in indoor occupational settings, uneven ground surfaces are commonly seen in the agriculture (Zhao, Upadhyaya, and Kaminaka 1987), construction (Simeonov et al. 2003) and fishing (Ning and Mirka 2010) industries. A few recent studies have evaluated the effect of variable ground surfaces on the behaviour of lumbar musculature. A significant effect of the laterally slanted ground surface on the activity of contralateral and ipsilateral back extensor muscles was reported by Jiang et al. (2005) during a static lifting task. Another study which investigated the effect of ground rolling motion on bilateral low back muscle activity during lifting on a simulated boat (Ning and Mirka 2010) demonstrated clear differences between the bilateral trunk extensor muscles with the lateral angular displacement of the ground surface. In the same study, an elevated trunk muscle co-contraction was also observed which has been shown to increase spinal loading (Granata and Marras 1995) and thereby elevate the risk of LBP (Chaffin and Park 1973; Neumann et al. 1999). Based on the results of these previous studies, we suspected that a laterally slanted ground surface could alter the load-sharing mechanism between the active and passive tissues of the low back during full trunk flexion motions.

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The lumbar spine has a sophisticated structure with a number of active tissues (muscles) and passive tissues (vertebrae, discs, ligaments and fascia). Lumbar and trunk motions are facilitated by the interaction of these tissues. An improved understanding of the synergy between active and passive lumbar tissues is critical for the assessment and control of low back injuries. Previously, the lumbar muscle flexion–relaxation phenomenon (FRP) has been used to study the interaction between active and passive lumbar tissues (McGill and Kippers 1994; Shan et al. 2012). This phenomenon describes the sudden cessation of lumbar extensor muscle activity at close to full-flexion posture during trunk flexion and extension motions (Floyd and Silver 1955). Previous studies have made extensive efforts in investigating lumbar FRP while standing on flat, even ground surfaces (Sarti et al. 2001; Solomonow et al. 2003; Shin, D'Souza, and Liu 2009; Ning et al. 2011). However, despite a strong evidence that variable ground conditions impact the lumbar muscle activation patterns (Jiang et al. 2005; Ning and Mirka 2010), the effect of laterally slanted ground surfaces on the lumbar FRP has not been well understood. The objective of this study was to evaluate the effect of laterally slanted ground surface on the flexion–relaxation responses of the low back musculature. It was hypothesised that the change in lateral ground surface angle will create discrepancy in bilateral lumbar muscle FRP during trunk flexion–extension motion.

2. Methods

2.1. Participants

Fourteen male participants were recruited from the student population at West Virginia University. Participants were an average of 27.4 (SD 3.1) years old, with a height of 176 (SD 4.9) cm and a weight of 71 (SD 9.2) kg. All participants were free from chronic low back disorder or chronic lower extremity injury. Because standing on a laterally slanted ground surface may increase the risk of falling, participants with balance disorders were also excluded from this study. In addition, female participants were excluded from the current study in order to eliminate the potential confounding gender effect. The experiment procedures were approved by the West Virginia University Institutional Review Board. Written informed consent was obtained from all participants prior to the data collection.

2.2. Instrumentation and apparatus

Muscular activity was sampled from the lumbar paraspinal muscles at the L3 and L4 vertebrae levels using a surface electromyography (EMG) system (Bagnoli, Delsys, Boston, MA, USA). Bipolar surfaced EMG electrodes were placed 4 cm lateral from the L3 spinous process and 2 cm lateral from the L4 spinous process. The EMG signals were sampled at 1024 Hz. Participants' trunk kinematics data were collected using a magnetic field based motion tracking system (Motion Star, Ascension, Burlington, VT, USA). Three magnetic sensors were attached to the skin surface over the C7, T12 and S1 vertebrae levels. During the data collection, the three dimensional coordinates and the sagittal, coronal and rotational angles of each motion sensor (with regard to the centre of the magnetic field) were recorded with a sampling frequency of 102.4 Hz. The EMG and trunk kinematics data were synchronised and preprocessed using MotionMonitor software (Model MotionMonitor, Innovative Sports Training, Chicago, IL, USA). Participants' maximum voluntary contraction data of the lumbar muscles were collected using a dynamometer (HUMAC Norm, Computer Medicine, Stoughton, MA, USA). Custom-made wood structures were used to provide the laterally slanted ground surfaces (15° and 30°) (Figure 1). Anti-skid strips were attached to the wood surface in order to provide a high coefficient of friction and reduce the risk of falling. In addition, participants' stance width (distance between the centre lines of their shoes) was controlled at their shoulder width across all conditions.

2.3. Experimental design

The ground surface angle (ANGLE) was the only independent variable involved in this study and was tested at three levels: 0° (flat ground), and 15° and 30° (laterally slanted ground). The slanted angle in this experiment was defined as the angle between the ground surface and the horizontal plane. During the data collection, participants were instructed to always have their right foot placed at the higher position on the slanted surface (Figure 1). Muscles on the right and left side, respectively, referred to as the contralateral and ipsilateral sides in regard to the direction of the slanted surface.

Ten dependent variables were considered in this experiment and can be divided into two categories: lumbar flexion angle and trunk inclination angle. Lumbar flexion angle was defined as the angular difference between the pitch angles (in the sagittal plane) of the T12 and S1 motion sensors; trunk inclination angle was defined as the angle between the vertical (normal) line and the line between the C7 and S1 motion sensors (Figure 2) (Ning et al. 2011). A natural upright posture generates a near-zero trunk inclination angle and a negative lumbar flexion angle, which represents the lordosis of the

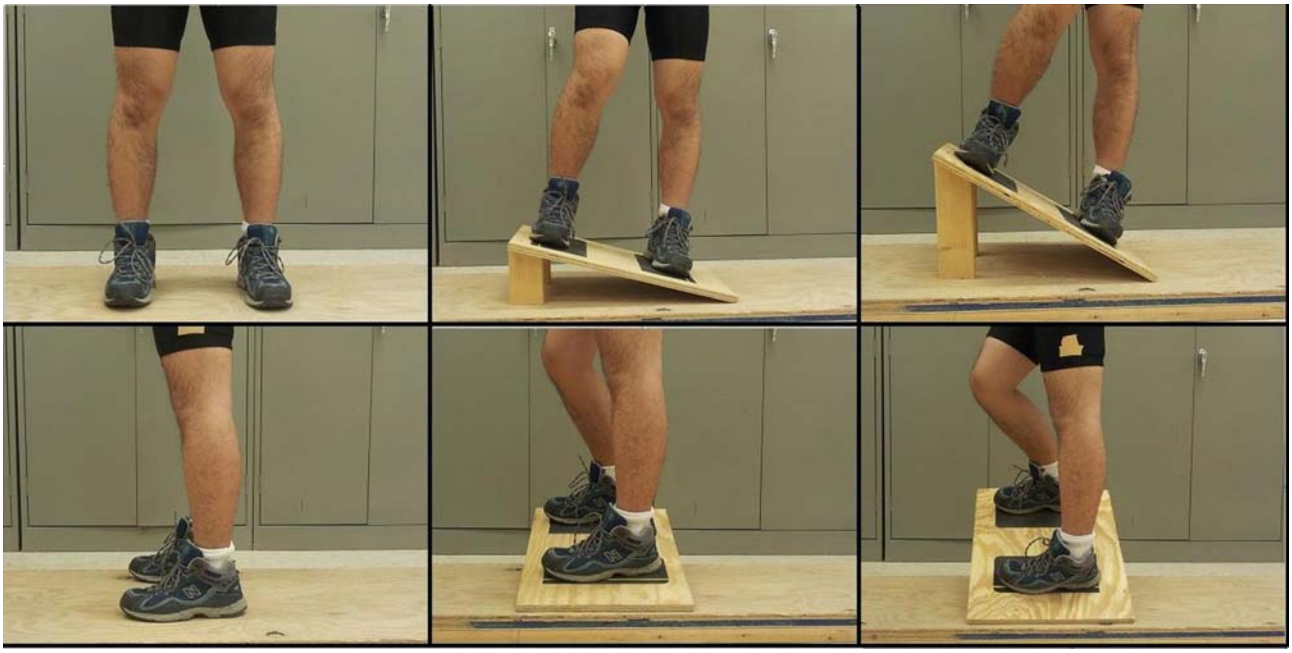

Figure 1. Frontal and side views of the ground conditions (left panel, flat; centre panel, 15° slanted; right panel, 30° slanted).

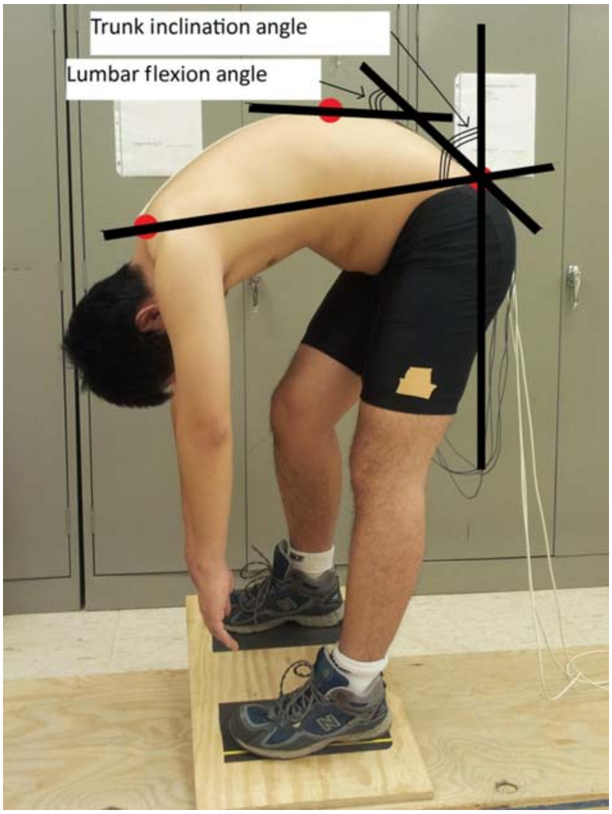

Figure 2. Illustration of lumbar flexion angle and trunk inclination angle.

lumbar spine. The first two dependent variables were the maximum lumbar flexion angle and the maximum trunk inclination angle which were defined as the peak angles at the full-flexion posture. The other eight dependent variables were defined as the corresponding lumbar flexion and trunk inclination angles at the onset point of FRP during trunk flexion motion for the four sampled low back muscles (ipsilateral L3 paraspinals, contralateral L3 paraspinals, ipsilateral L4 paraspinals and contralateral L4 paraspinals). The onset point of FRP is referred to as the 'EMG-off' point to better reflect the cessation of muscular EMG activity at the beginning of FRP.

2.4. *Protocol*

Upon arrival, the experimental procedure was described to the participant followed by a brief (5 min) warm-up session. Surface electrodes and motion sensors were then secured to the designated locations using double-sided tape. During the data collection, each participant performed a total of 15 trunk flexion–extension motions (three ANGLE conditions with five repetitions in each condition) in a random order. The protocol required participants to perform a slow and smooth trunk flexion–extension motion: 7 s to flex the trunk from upright standing to the full-flexion posture, 6 s in full-flexion posture and 7 s to come back to the upright standing position. The full-flexion posture was defined as the maximum trunk flexion one can maintain with all trunk muscles relaxed. A metronome was used to assist participants in controlling the pace of their motions. At least 1 min of rest was provided between trials in order to avoid the effect of lumbar muscle fatigue and viscoelastic changes of posterior lumbar tissues.

2.5. *Data processing*

The unprocessed EMG data were first filtered with a high-pass frequency of 10 Hz, a low-pass frequency of 500 Hz and a notch filter of 60 Hz and its aliases. The data were then full wave rectified; a half second (512 data points) moving window was developed to generate a standard deviation (SD) profile for each muscle. The SD at full-flexion posture was used as the full-flexion standard deviation (FSD). The SD profile from each muscle was then compared with its corresponding FSD in order to identify the onset and cessation of FRP. The detail of this algorithm was described in the previous study (Ning et al. 2011). In short, the last point where the muscle SD profile is larger than 3*FSD during trunk flexion was defined as the EMG-Off point. The corresponding lumbar flexion and trunk inclination angles were defined as lumbar/trunk EMG-Off angles for each muscle (Figure 3).

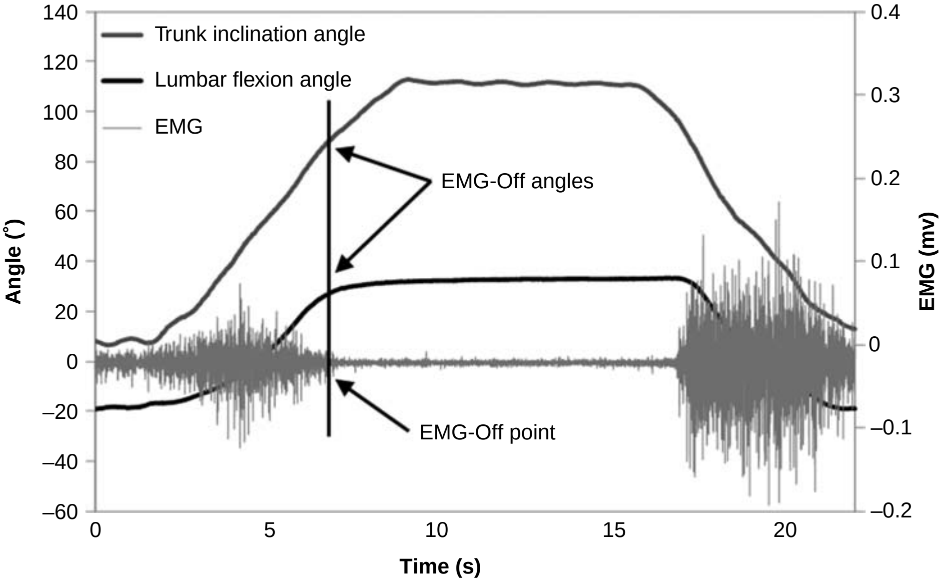

Figure 3. Demonstration of a typical lumbar muscle EMG signal, lumbar flexion angle and trunk inclination angle profiles during trunk flexion–extension motion. The EMG-Off point is also shown.

2.6. *Statistical analysis*

In the current analysis, each repetition was treated as a single observation. Prior to any statistical analysis, the assumptions of the analysis of variance (ANOVA) procedures (i.e. independence of observations, constant variance of residuals and normal distribution of residuals) were tested; variables that did not satisfy one or more assumptions were transformed to meet the criteria (Montgomery 2005). The effect of ANGLE on each dependent variable was then investigated using repeated measures ANOVA with 'subject' considered as a random factor. To further identify the differences between the three ANGLE conditions, a Tukey–Kramer post-hoc test was used on the dependent variables that were significantly affected by ANGLE. Finally, paired *t*-tests were conducted to investigate the differences between the EMG-Off angle between the right side and left side of the low back muscles. The criteria *p*-value was 0.05 for all statistical analysis.

3. Results

The EMG data demonstrated that the FRP consistently occurred in all four back muscles in all conditions. Results of the statistical analysis revealed that the maximum lumbar flexion angle was not significantly affected by ANGLE, but the maximum trunk inclination angle was significantly lower in the 30° ground angle condition (on average 2.8° lower than flat ground condition) (Figure 4), because participants' bended right knee would physically limit the range of trunk motion. The increase in ANGLE significantly reduced the lumbar EMG-Off angle on the ipsilateral (left) side of both the L3 and L4 paraspinals (Figure 5), whereas the contralateral (right) side was not affected. In terms of trunk EMG-Off angle, the

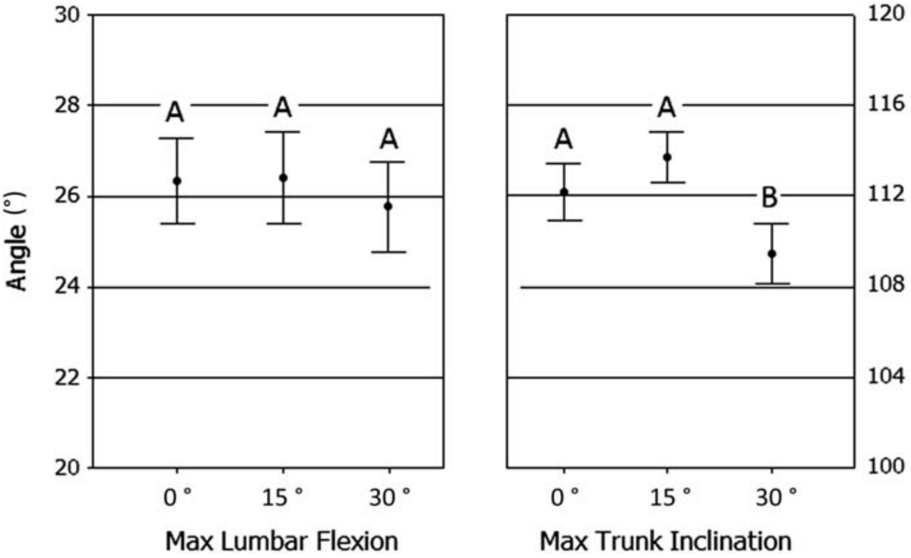

Figure 4. Maximum lumbar flexion angle (left panel) and maximum trunk inclination angle (right panel) under different ground conditions. Different letters denote angles that are statistically different from one another. Bars indicate the corresponding standard error.

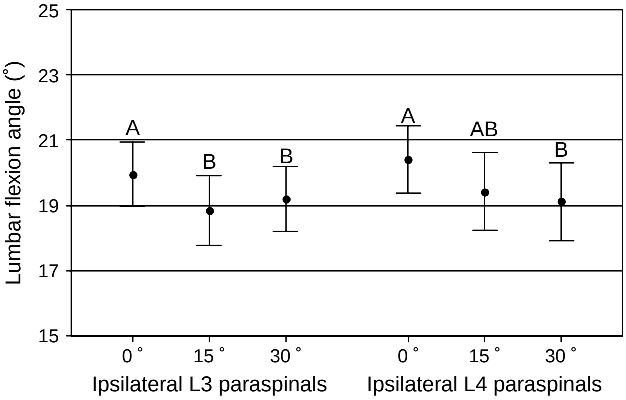

Figure 5. Lumbar EMG-Off angle for the ipsilateral (left) side of L3 and L4 paraspinals under different ground conditions. Different letters denote angles that are statistically different from one another. Bars indicate the corresponding standard error.

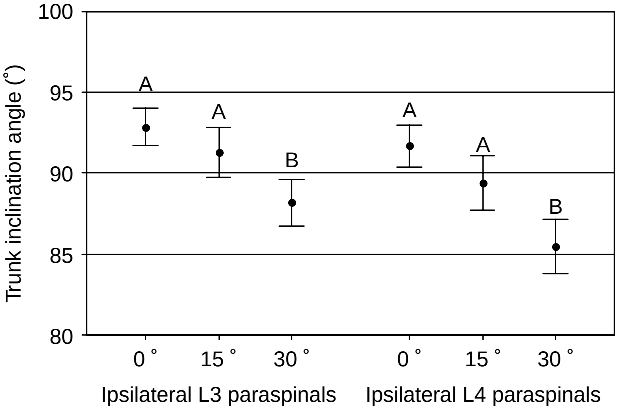

Figure 6. Trunk EMG-Off angle for the ipsilateral (left) side of L3 and L4 paraspinals under different ground conditions. Different letters denote angles that are statistically different from one another. Bars indicate the corresponding standard error.

Table 1. The EMG-Off angle difference (right minus left) between bilateral L3 and L4 paraspinals.

	L3 paraspinals (difference)				L4 paraspinals (difference)			
Angle	Lumbar EMG-Off		Trunk EMG-Off		Lumbar EMG-Off		Trunk EMG-Off	
0°	− 0.1°	$p = 0.68$	0.1°	$p = 0.91$	0.0°	$p = 0.72$	− 0.2°	$p = 0.77$
15°	**1.9°**	$\boldsymbol{p < 0.0001}$	**3.7°**	$\boldsymbol{p = 0.017}$	**1.1°**	$\boldsymbol{p < 0.0001}$	**1.8°**	$\boldsymbol{p = 0.043}$
30°	**2.0°**	$\boldsymbol{p < 0.0001}$	**3.9°**	$\boldsymbol{p < 0.0001}$	**1.7°**	$\boldsymbol{p < 0.0001}$	**2.8°**	$\boldsymbol{p = 0.001}$

Note: Bolded numbers indicate that results are significantly different from zero.

ipsilateral (left) side of both the L3 and L4 paraspinals demonstrated significantly lower values with the increase in ANGLE (Figure 6). However, different from the results of the lumbar EMG-Off angles, the contralateral sides of both muscles indicated significantly lower trunk EMG-Off angles in the slanted ground angle conditions. This difference could be attributed to the lower maximum trunk inclination angle at these conditions.

Results of the paired *t*-test discovered significantly different lumbar and trunk EMG-Off angles between the ipsilateral and contralateral sides of both the L3 and L4 paraspinals under both slanted ground conditions (Table 1). Our findings suggest that when performing deep trunk flexion motion on laterally slanted ground surfaces, the ipsilateral lumbar muscles will always cease activity earlier than the contralateral lumbar muscles. Results in Table 1 demonstrate the angular differences between the contralateral and ipsilateral lumbar muscle EMG-Off angles. As shown in the table, these angular differences were more pronounced among the L3 paraspinals than the L4 paraspinals (e.g. at 15° slanted ground condition, 3.7° versus 1.8° trunk EMG-Off angle difference between the bilateral L3 and L4 paraspinals, respectively).

4. Discussion

Results of the current study supported our initial hypothesis. More specifically, we found that the ipsilateral side of the L3 and L4 paraspinals will cease activity earlier (Figures 5 and 6) under the slanted ground conditions. Two possible mechanisms could explain this change. First, we discovered a small but significant rightward shift of the C7 motion sensor during trunk flexion under the two slanted ground conditions (Figure 7). This displacement in the mediolateral direction indicates a shift of trunk motion toward the right foot which results in a slight asymmetric bending motion. Although the motion was designed to be sagittally symmetric, when performing trunk flexion on laterally slanted surfaces, participants may have adopted a slight asymmetric trunk posture as a strategy to maintain balance. This slight change in posture, although barely notable, could influence the back muscle activity patterns. Previously, Ning et al. (2011) reported that asymmetric trunk flexion introduces greater tension to the lumbar posterior tissues on the opposite side of asymmetry (in this case the left side) leading to an earlier onset of muscle relaxation. Results of the current study also supported this previous finding. Second, compared to the flat ground condition where both legs were kept straight, under the laterally slanted ground conditions the straight (left) leg could experience higher stress and strain due to the flexed knee of other (right) leg. From a pure anatomical point of view, this increase in strain would increase the tension on the hamstring muscles

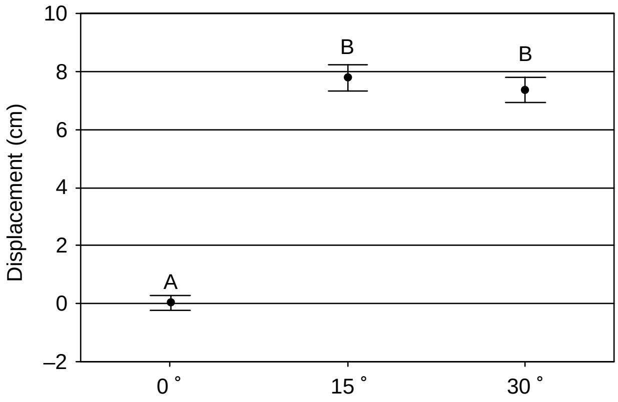

Figure 7. Mediolateral displacement (positive value indicates rightward shift) of C7 motion sensor during trunk flexion motion. Different letters denote displacements that are statistically different from one another. Bars indicate the corresponding standard error.

(e.g. biceps femoris) which could reduce forward pelvic rotation and increase the tension on lumbar posterior ligaments and the passive tension on the lumbar extensor muscles (Shin et al. 2004). This increased lumbar ligament tension could cause an early cessation of activity for lumbar muscles on the ipsilateral side.

The FRP of paraspinal muscles at the L3 and L4 on the contralateral side was also affected by the slanted ground surfaces. As noted, participants in this study maintained a flexed right knee posture while standing on laterally slanted ground surfaces. The flexion of knee is known to cause a forward pelvic rotation (Murray et al. 2002), which reduces the tension on passive lumbar tissues and should therefore delay the onset of FRP for the lumbar muscles on the corresponding side. In other words, to compensate for the reduction of the passive tissue loading, the lumbar muscles need to exert more force for a longer duration during the trunk flexion motion. Results of our study partially supported this assertion. The L3 contralateral (right side) and L4 paraspinals' lumbar EMG-Off angles demonstrated a small but steady increase from 19.9° to 21.1° and 20.3° to 20.8°, respectively, with an increase in slanted ground angle. This is consistent with the findings of Shin et al. (2004). However, the observed effect was statistically not significant, possibly due to the relatively small knee flexion angles adopted by the participants. Future investigation on larger slanted ground angles (i.e. more than 30°) may reveal significant differences.

The comparison between the bilateral L3 and L4 paraspinals revealed that the ipsilateral lumbar muscles cease activity earlier than the contralateral lumbar muscles. This difference is more pronounced among the L3 paraspinals than the L4 paraspinals (Table 1). A previous study reported that the laterally located back muscles are more affected by asymmetrical motion during trunk bending (Ning et al. 2011). In the current study, the EMG sensors on the L3 paraspinals were more laterally located than the L4 paraspinals (4 cm vs. 2 cm away from the mid-line of spinal column). This coupled with the slight rightward bending adopted by the participants during the trunk flexion motion may have produced the EMG-Off angle difference between the bilateral L3 and L4 paraspinals. Furthermore, according to lumbar spine anatomy and the sampling locations of the L3 and L4 paraspinal muscles, it was suspected that the recorded EMG signals from the L3 level may primarily come from more laterally located lumbar extensor muscles such as the longissimus and iliocostalis and signals from the L4 level may mainly come from more medially located muscles such as the multifidus. The longissimus is considered a global muscle with a primary function of providing the necessary force and moment during trunk motion (Bergmark 1989). On the other hand, the multifidus is considered as a local lumbar muscle with a primary function of maintaining lumbar stiffness and stability (Ward et al. 2009). It is likely that the local muscles are less responsive to the global trunk motion in response to slanted ground surfaces.

Three limitations of the current study need to be pointed out. First, to reduce the risk of falling, a maximum slanted ground angle of 30° was tested; however, certain occupations may require performing manual material handling tasks on more steeply inclined ground surfaces. Knee flexion had a relatively small impact on the maximum trunk inclination angle and low back muscle EMG-Off angles, but it is our suspicion that with the further increase in the slanted ground angle, trunk kinematics could be significantly affected by the changes in lower extremity posture and augment the spinal instability. Second, participant's stance width was kept constant in all three ground conditions. However, due to the effect of the laterally slanted surface, the corresponding leg opening angles may change which could affect lifting biomechanics (Sorensen et al. 2011) and possibly the flexion–relaxation responses of the lumbar muscles. A future study should quantify the effect of stance width on lumbar FRP. Third, participants were all college students. This sample group was relatively fit and lacking in real occupational experience of working on uneven ground surfaces. Therefore, their biomechanical responses (trunk kinematics, foot-weight distributions, muscle activation patterns, etc.) could be different from workers who constantly work on laterally slanted surfaces (e.g. roofers).

5. Conclusions

In conclusion, when performing trunk flexion–extension motions on laterally slanted ground surfaces, the ipsilateral lumbar muscles will cease activity earlier than the contralateral side. The increase in laterally slanted ground angle enlarges this difference and reduces the maximum trunk flexion angle. In addition, laterally located lumbar muscles tend to have larger bilateral EMG-Off angular differences compared with medially located lumbar muscles. In summary, when performing repetitive bending or lifting tasks on a laterally slanted surface, the contralateral lumbar muscles will activate for a longer period of time and could, therefore, reach fatigue sooner than the ipsilateral lumbar muscles.

Notes

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