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Compensatory behavior of the postural control system to flexion–relaxation phenomena

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Summary Laxity of the passive tissues of the spine during prolonged spinal flexion has been shown to disturb spinal stability. This study investigated the effects of short periods of static lumbar flexion and short rest periods on the flexion–relaxation angle for the erector spinae muscles in 36 healthy female college students. The surface electromyographic activity of the erector spinae muscles was measured in three states before the onset of creep, immediately after 7 min of static lumbar flexion, and after a 10 min rest. The results showed that 7 min of static lumbar flexion will produce relaxation of the erector spinae muscles that occurs at greater absolute lumbar and trunk angles, during the forward bending activity ($P < 0.05$), while the corresponding relative angles did not change before and after creep.

The results also indicate that postural compensations are dominant over the muscular compensations for load sharing in flexion–relaxation phenomena of asymptomatic healthy participants. This further highlights the importance of postural modulation in the control of movement and preservation of skeletal stability.

Clinical relevance: Considering spinal posture in the upright condition, and its changes by phenomena such as creep, can reduce postural injuries by instructing subjects to approach a more vertical posture, after periods of bending, to compensate the stretching effects of the tissues and thus regaining the normal muscular activity pattern.

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Introduction

Creep deformation in the various passive tissues of the spine including ligaments, intervertebral discs, and joint capsule is thought to increase the laxity of the intervertebral joints, allowing increased relative motion, which destabilizes their natural alignment, with the potential for consequent injury and associated pain (Jackson et al., 2001; Solomonow et al., 1999; Wiliams et al., 2000). High incidence of low back pain (LBP) disorders is associated with occupations requiring sustained and repetitive lumbar flexion (Little and Khalsa, 2005). As the trunk is flexed from a standing position toward full lumbar flexion, lumbar extensor muscles exhibit myoelectric silence and this phenomenon is called flexion—relaxation (FRP) (Floyd and Silver, 1955; Kippers and Parker, 1984; Olson et al., 2004). In the fully flexed posture, the body weight is supported mainly by a passively generated extension moment from spinal ligaments, intervertebral discs and the passive components of the extensor muscle-tendon units (McGill and Kippers, 1994). If the flexed posture is maintained, the passive tissues will deform at a slow rate due to their viscoelastic material properties, and this creep deformation of the spinal tissues provides more laxity in the passive tissues and reduced resistance to forward flexion moment (Shin and Mirka, 2007). The change in the passive tissue stiffness is expected to affect the activation level of back extensor muscles because flexion moment generated by upper body weight is supported by co-contribution of both active and passive components.

The creep response and recovery behavior of erector spinae is an interesting model to study the modulation of lumbar stability. Solomonow et al. (2003a) showed creep, developed during a short static lumbar flexion, elicited significant changes in the muscular activity pattern of the flexion—relaxation phenomenon. The effects of creep on the upright posture and considering this in EMG activity of erector spinae have not yet been fully identified. Understanding how the trunk and lumbar angles are affected by the creep phenomenon and how the erector spinae muscles activation pattern is influenced by these changes, can be helpful in the assessment of the creep phenomenon and choosing a preventive strategy for low back pain.

The aims of this study were to investigate how a short static posture of 7 min affects the absolute and relative angles of flexion—relaxation response and how a short rest period of 10 min would moderate those effects. Since considering the starting posture while measuring range of motion is of great importance (Vachalathiti et al., 1995), it was presumed that using the two measures of "absolute" and "relative" angles would lead to different results, therefore in this study, we have chosen the latter to get a better estimate of the effect of creep phenomenon on spinal motion characteristics, while keeping the absolute value for comparative purposes.

Methods

Subjects

Thirty-six healthy female students without a history of back pain during the last 2 years were recruited from Tehran university of Medical Science and Health Services to participate. All participants were free from chronic and current back problems and after being introduced to the nature of the study, signed consent forms that they were willing to take part. Previous studies have shown the creep-related changes to be different in males and females (Solomonow et al., 2003a). Thus to neutralize the effect of gender and its consequent confounding factors, and also since they were more accessible, only females were studied.

The mean (standard deviation) age, height and weight of the thirty-six participants were 22.3(3.4) years, 1.6(0.1) m and 56.7(6.3) kg, respectively.

Instrumentation

Surface EMG data were collected using a 4-channel electromyography device (Medelec, Promiere model). The EMG signals were detected by pregelled Ag—AgCl electrode pairs applied at the L3-4 level over the left erector spinae musculature (about 4 cm lateral from midline). Center to center electrode distance was 2.5 cm; electrodes were longitudinally oriented along the fibers of the erector spinae muscles. A reference electrode was taped on the left wrist. To identify the L3 level we first found the sacrum and followed the spinous processes of the lumbar vertebrae up to L3. L3 is located at the center of the lumbar curvature and due to its long transverse processes, provides mechanical advantage for the muscles so the investigation of muscular activity at this level is preferred (Bogduk, 1997) and it is more comparable to other research reports (Solomonow et al., 2003a).

The EMG signals were amplified by 1000 with a frequency band pass of 20—500 Hz, Gain 100 μV/Div., 80 dB signals to noise ratio and CMRR of 90 dB. Maximum acceptable skin impedance level was set at 5 kΩ. Sampling rate of recording was 1000 Hz and the data were digitized and stored by a 12-bit A/D board.

Angular variables were estimated by a digital camera (JVC-GZ-MG50AS) placed 1 m away from the subject at waist level with a direct view of the subject's right side in the sagittal plane. The camera collected kinematics data at the rate of 25 frames per second. The markers used to measure the segment angles were attached to the subjects as follows: three circular markers were attached to the right greater trochanter, lateral midline along the iliac crest and the lower palpable edge of the rib cage (Solomonow et al., 2003a). Video and EMG data were synchronized by an electrical circuit which triggered them at the same time.

Protocol

The skin was cleaned with alcohol preparation pads before attachment of the EMG electrodes. The electrodes and skin markers were placed as described above, and the signal was checked prior to test trials to make sure of proper marker detection and lack of EMG signal noises. The subjects stood just behind a horizontally drawn line on the ground barefoot with their feet pelvis-width apart, their wrists hooked together in the front of their body, and their knees kept straight and bent forward from the waist level as far as possible. After introducing the task to the subjects and making sure of the accuracy of the maneuver, subjects performed two trials separated by 30—50 s between them. Each trial consisted of an approximately 3 s of quiet standing followed by 3—5 s full forward flexion. The deep flexion was held for 4 s followed by 3—5 s extension to upright posture, and then static standing through the end of recording. Finally one of the trials was chosen depending on signal quality for data analysis (Hashemirad et al., 2009).

After recording EMG and kinematics data, the subjects sat on the floor with their trunk in full lumbar flexion. A hemicylindrical foam bolster was placed under the thighs to tilt the pelvis posteriorly, and reduce hamstring stretch (Solomonow et al., 2003a) (Figure 1). The subjects stayed in this static flexion position for 7 consecutive minutes, immediately after which they stood up and performed another set of flexion—extension tasks similar to the one performed prior to the static flexion period. Following that the subjects sat on a chair to recover for 10 min and then the trial, and recordings of EMG and kinematics were all repeated.

Data analysis

The recorded EMG signals were full-wave rectified and smoothed with the time constant of 50 ms to yield linear envelops. The EMG values were normalized using the peak EMG magnitude during the task. A threshold level of 5% of this magnitude was used to determine the onset and the end of the flexion—relaxation period. The onset of the flexion—relaxation phenomenon (EMG-Off) was defined as the point at which the magnitude of EMG signal got less than the threshold level and the end point of the phenomenon (EMG-On) during the extension phase was defined as the point at which EMG signals amplitude exceeded the threshold level (Olson et al., 2004) (Figure 2).

The video data were analyzed using Ulead video studio software (version 7) to match the frame of the video with the corresponding EMG signals (frames of EMG-Off and EMG-On). Measurement of the angles of interest in each specific frame was done with Auto CAD software (2006).

The trunk, hip and lumbar angles were measured by lateral markers. Trunk angle was defined as the angle between the vertical line crossing the ilium marker and the line connecting the rib and ilium markers. The hip angle was defined as the angle between the vertical line crossing the ilium marker and the line connecting the greater trochanter and ilium markers while the angle of lumbar flexion was defined as the difference between the two previous ones (trunk angle – hip angle) (Solomonow et al., 2003a) (Figure 3). The angle measurements were done as absolute and relative. The relative angles were calculated with respect to the corresponding angles in the erect posture.

The dependent variables included absolute and relative angles of the trunk and lumbar in full flexion, EMG-On and EMG-Off, in three conditions of before, immediately after and 10 min after the creep.

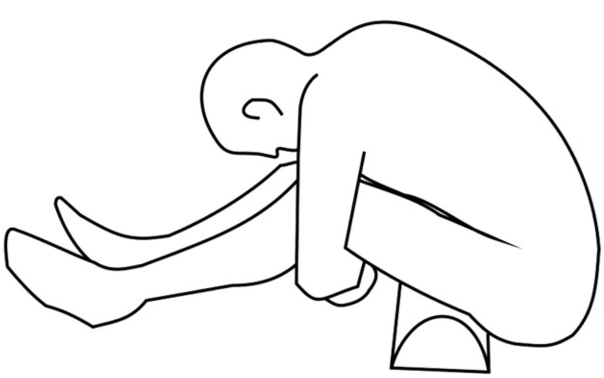

Figure 1 Schematic representation of a subject during the 7 min of static lumbar flexion.

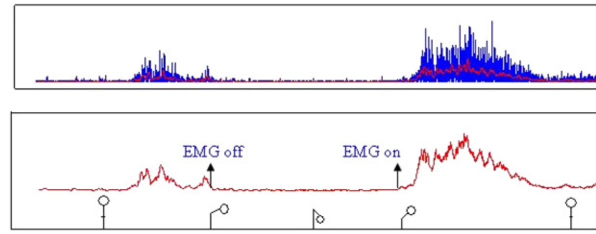

Figure 2 Typical recording of EMG activity during the flexion—extension task. Raw EMG and the linear envelope data were used to estimate EMG-Off and EMG-On points. The extension phase used for normalization of the EMG linear envelope is also provided.

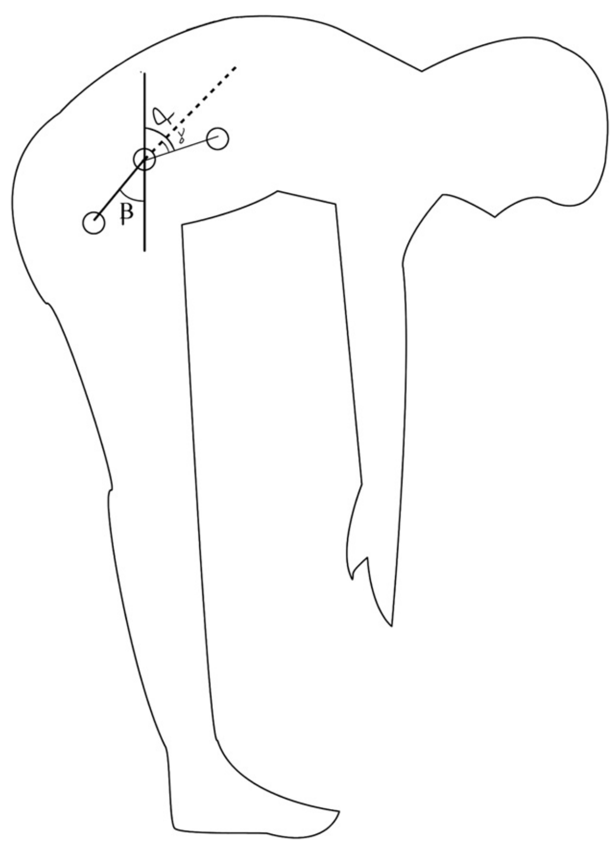

Figure 3 Schematic representation of a subject performing the forward bending task and the measured angles where α, β and γ are the trunk, hip and lumbar angles, respectively.

Table 1 The effect of creep phenomenon on absolute angles at full flexion, EMG-Off and EMG-On in 21 subjects who exhibited FR before and after creep.

Parameters (absolute angles)	Before creep (condition I) X(SD)	After creep (condition II) X(SD)	After 10 min rest (condition III) X(SD)	P value		
				Conditions I,II	Conditions I,III	Conditions I,III
Trunk angle						
Full flexion	103.3(17.1)	106.4(17.7)	106.1(17.7)	**< 0.001**	**0.008**	0.738
EMG-off	102.7(16.8)	106.1(17.9)	105.5(18.1)	**< 0.001**	**0.009**	0.577
EMG-on	83.9(14.8)	84.7(20.4)	87.1(22.2)	0.752	0.328	0.316
Lumbar angle						
Full flexion	48.6(9.0)	50.5(9.4)	50.1(9.7)	**0.009**	**0.011**	0.534
EMG-off	48.6(8.9)	50.4(9.4)	50.03(9.9)	**0.015**	**0.010**	0.547
EMG-on	45.6(8.7)	46.2(10.1)	46.8(9.8)	0.528	0.187	0.449

Statistical analysis

Analysis of variance with repeated measures design (before vs. after 7 min of deep flexion and 10 min of rest) was used to evaluate the effect of static flexion on EMG activity pattern of erector spinae muscles. The alpha level was set at 0.05.

Results

Thirty of the 36 subjects (or 83%) exhibited FRP in their erector spinae muscles before creep. Nine out of 30 subjects did not show FRP after the creep. The data from 21 of these subjects who also showed FRP after static lumbar flexion were subjected to statistical analysis. Since the focus of this study was on investigating the effect of creep on the flexion—relaxation phenomenon, the data from 15 subjects who did not exhibit this phenomenon were not analyzed here.

Table 1 demonstrates the test results of the absolute trunk and lumbar angles in full flexion, EMG-On and EMG-Off in three conditions of before, immediately after and 10 min after the creep. 7 min of static lumbar flexion increased trunk and lumbar angles for 3.4° (from 102.7° to 106.1°) and 1.8° (from 48.6° to 50.4°) at the EMG-Off point ($P < 0.05$). There was no difference between immediately after creep and after the 10 min rest period. After the creep, the erector spinae muscles remained active in larger degrees of flexion and the creep response was not fully recovered after 10 min of rest.

Table 2 indicates of the trunk and lumbar angles in the erect posture in three conditions of before, immediately and 10 min after the creep. 7 min of static lumbar flexion led to 2.6° (from 13.5° to 10.9°) and 1.7° (from 4.7° to 3.0°) decrease in the trunk and lumbar angles, respectively ($P < 0.05$) and following this period of rest, the approximation of the angles to the reference vertical did not fully recover.

Table 3 shows the results related to the relative angles in three conditions of before, immediately and 10 min after the creep. To calculate the relative angles, the absolute trunk and lumbar angles at the EMG-Off and EMG-On points were compared to the corresponding values in the erect posture which yielded no significant difference between the relative angles before and after the creep. In other words according to the relative angles, the erector spinae muscles were relaxed at the same angles in the before and after creep conditions.

According to Tables 1 and 3, there was no significant difference in EMG-On angles for both absolute and relative measures. In other words, 7 min of static lumbar flexion had no significant effect on re-activation of the erector spinae muscles in the extension phase.

Discussion

Differences seen in the responses of FRP in angle measurements as absolute and relative, showed that the changes in the trunk and lumbar angles in the erect posture offset the creep-related increase in absolute angles of EMG-Off so that relative angles did not show significant difference before and after the creep.

Solomonow et al. (2003a) in a similar study found the changes in trunk and lumbar angles of the 25 female participants to be 7.3° and 2.7°, respectively at the EMG-off point. Our results follow the same trend with the absolute values of the corresponding angles to be 3.4° and 1.8°, respectively, while in both studies these changes were statistically significant. In contrast, the angular changes at the point of EMG-on in our study were not statistically meaningful while Solomonow found them significant in his study. Based on the results of this study, it seems that EMG-Off angles were more sensitive than EMG-On angles because the shorter time of static lumbar flexion only provokes changes in the absolute angles at which the EMG turns off.

Table 2 The effect of creep phenomenon on angles at erect posture in 21 subjects who exhibited FR before and after creep.

Parameters in erect position	Before creep (condition I) X(SD)	After creep (condition II) X(SD)	After 10 min rest (condition III) X(SD)	P value		
				Conditions I,II	Conditions I,III	Conditions I,III
Trunk angle	13.5(7.3)	10.9(7.8)	11.3(6.8)	**< 0.001**	**0.002**	0.714
Lumbar angle	4.7(6.6)	3.0(7.7)	2.1(7.2)	**0.001**	**0.001**	0.235

Table 3 The effect of creep phenomenon on relative angles at full flexion, EMG-Off and EMG-On in 21 subjects who exhibited FR before and after creep.

Parameters (Relative angles)	Before creep (condition I) *X*(SD)	After creep (condition II) *X*(SD)	After 10 min rest (condition III) *X*(SD)	*P* value		
				Conditions I,II	Conditions I,III	Conditions I,III
Trunk angle						
Full flexion	116.9(17.1)	117.4(18.7)	117.4(16.7)	0.519	0.680	0.992
EMG-off	116.3(16.9)	117.0(18.9)	116.8(17.1)	0.389	0.733	0.878
EMG-on	97.5(12.9)	95.7(20.7)	98.4(21.1)	0.520	0.768	0.163
Lumbar angle						
Full flexion	53.4(8.2)	53.5(8.8)	52.2(8.2)	0.867	0.109	0.241
EMG-off	53.4(8.4)	53.4(8.7)	52.1(8.3)	0.962	0.088	0.240
EMG-on	50.4(7.4)	49.2(9.2)	48.9(7.9)	0.277	0.143	0.852

It seems that static lumbar flexion for durations for as long as 7 min, will impose alterations in the spinal system which, if not compensated by the spinal stabilizing system (such as changing the erect standing posture as the starting and reference position) might challenge the stability of the system.

Panjabi has divided the spinal stabilizing system into active, passive and neural sub-systems. In the normal state, the three sub-systems work together to provide the needed mechanical stability (Panjabi, 1992). Since the FRP is the product of interplay between active and passive elements of the spine, the unchanged behavior of the phenomenon indicates that the alterations in the erect starting position of the spine provides enough passive tension in the posterior elements for the FRP to occur, and the erector spinae muscles to relax at the same relative angles.

Considering the effects of static lumbar flexion on erect posture, an important suggestion can be constructed from the findings of this study: when the lower back is exposed to static loading due to activities such as manual material handling, the process of muscle recovery can be substantially improved by modulating the starting erect posture to decrease the developed laxity in the passive tissues.

The findings of this study confirm the results of previous ones, showing that creep and increased muscular activity that were developed during the 7 min of flexion, were not fully recovered by the 10 min rest period (Shin and Mirka, 2007; Solomonow et al., 2003b; Solomonow, 2004). Following these results, it emerges that the rest duration of 10 min is not capable of allowing full recovery, even if a static lumbar flexion of less than 10 min is applied to the lumbar spine.

As elicited in the results of this study, six of the 36 subjects (or 17%) before creep and nine of the 30 subjects (or 30%) after creep despite being asymptomatic did not exhibit FRP. This heterogeneity in the healthy population might shed light on the predisposing factors and development mechanisms of LBP which seems worth studying in prospective studies. Further study on the neurophysiologic aspects and reflex mechanisms associated with the creep phenomenon will add to the findings of this study.

Summary

Trunk and lumbar angles have achieved considerable attention in the assessment of body posture and spinal biomechanics. FRP has also been introduced as an effective factor influencing spinal stability and injury tolerance which can also show the acuity of the spinal performance as lack of this phenomenon has been associated with LBP. In this study, the effect of a short period static flexion posture (being critically important from an ergonomic point of view) has been investigated on the FRP and erector spinae muscles activation pattern. The results included three major interesting findings:

1) As per previous studies, ES muscles remained active for longer periods but, when considering the alterations of the upright standing posture at the starting position, it was revealed that short periods of static flexion do not alter the range of motion during which ES muscles are active.
2) 10 min of rest is not sufficient to offset the biomechanical consequences of 7 min of static flexion posture. It seems that a longer period of rest is needed to offset the effects of creep.
3) It seems that not only LBP patients fail to exhibit FRP but there are also subjects without low back problems, in which FRP is absent. A follow-up study might show if lack of FRP is a predictive factor for the incidence of LBP or not.

Conflict of interest statement

There is no conflict of interest regarding the publication of this paper.

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