Flexion–relaxation response to gravity

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Abstract

The objective of this report was to study the influence of the orientation of gravitational loading on the behavior of anterior and posterior trunk muscles during anterior trunk flexion–extension. Participants ($N = 13$) performed five (5) cycles of trunk flexion–extension while standing with gravity parallel to the body axis and five (5) cycles while in the supine condition (e.g.
sit-ups) with gravity perpendicular to the body axis. Surface electromyographic (EMG) patterns from lumbar paraspinal, rectus abdominis, external oblique, rectus femoris, semimembranosis, and biceps femoris muscles were analyzed during each condition. EMG signals were synchronized with lumbar flexion and trunk inclination angles. Flexion–extension from the standing position resulted in a myoelectric silent period of the lumbar posterior muscles (e.g.
flexion–relaxation phenomena (FRP)) as well as the hamstring muscles through deep angles during which activity was observed in abdominal muscles. Flexion–extension during sit-ups, however, resulted in a myoelectric silent period of the abdominal muscles and the quadriceps through deep angles during which the lumbar posterior muscles were active. In this condition, the FRP was not observed in posterior muscles. The new findings demonstrate the profound impact of the orientation of the gravity vector on the FRP, the abdominal muscles reaction to gravitational loads during sit-ups and its relationships with lumbar antagonists and thigh musculature. The new findings suggest that gravitational moments requirements dominate the FRP through the prevailing kinematics, load sharing and reflex activation–inhibition of muscles in various conditions. Lumbar kinetics or fixed sensory motor programs by themselves, however, are not the major contributor to the FRP. The new findings improve our insights into spinal biomechanics as well as understanding and evaluating low back disorders.

Keywords: Spine; EMG; Muscles; Flexion–relaxation

1. Introduction

The behavior of the lumbar paraspinal muscles has been studied previously during a variety of trunk movements, particularly cyclic trunk flexion–extension initiated from a standing position. Initially, a high level of electromyographic (EMG) activity can be observed in early flexion. This activity progressively decreases to a myoelectric silent period between mid-flexion and full trunk flexion angles (Ahern et al., 1988; Allen, 1948; Kippers and Parker, 1984; Portnoy and Morin, 1956; Schultz et al., 1985). Floyd and Silver (1955) termed the myoelectric silent period the 'flexion–relaxation phenomenon'. Allen (1948), Floyd and Silver (1955), and Golding (1952) hypothesized that tension in the stretching passive tissues (dorso-lumbar fascia and posterior ligaments) was sufficient to support the gravitational load of the trunk during deep flexion. This load sharing mechanism allowed the paraspinal muscles to decrease activity. Floyd and Silver (1951) also hypothesized that a neural reflexive response, from muscle spindles or joint...
receptors, influenced the myoelectric silent period as well.

The mechanical (Allen, 1948, Floyd and Silver, 1955, Golding, 1952) and neural mechanisms (Floyd and Silver, 1951) responsible for the flexion–relaxation phenomenon are supported in the literature. Questions remain as to the amount of influence each mechanism has on the behavior of the lumbar paraspinal muscles during trunk flexion. Human models (Andersson et al., 1996; Dickey et al., 2003; Golding, 1952; Kippers and Parker, 1984; McGill and Kippers, 1994; Solomonow et al., 2003) provide information supporting the mechanical load sharing hypothesis, while animal models (Claude et al., 2003; Sbriccoli et al., 2004; Solomonow et al., 1999; Williams et al., 2000) offer evidence regarding the occurrence of a neural adaptive response to changes in the mechanical properties of the passive tissues. Olson, et al. (2004) suggested that the mechanoreceptor afferents within the passive tissues contributed to an increased myoelectric silent period based on their human model observations. It is possible that both mechanisms work concomitantly, but the influence of each mechanism in regards to the myoelectric silent period is unknown.

These models provide a means of interpreting how the various tissues of the system interact and are affected by external stimuli. A significant factor in the human models has been the influence of gravity acting upon the trunk and the load. Based on previous studies (Lavender et al., 1992), the myoelectric activity of the lumbar paraspinal muscles may have been influenced by gravitational loading. The effect of gravity in the flexion–relaxation phenomenon hinders the understanding of the relative effect of multiple mechanisms thought to regulate the behavior of the lumbar muscles. For example, the posterior ligaments of the lumbar spine are expected to be strained during flexion from the upright position and during sit-ups. The mechano-receptors in the posterior ligaments are expected to elicit a reflexive activation or inhibition of the posterior muscles in a similar pattern. If the muscles, indeed, respond in a similar pattern in both conditions, one can assume that both mechanisms work concomitantly, but the influence of each mechanism in regards to the myoelectric silent period is unknown.

The purpose of this study was to explore the influence of the orientation of gravitational loading on the anterior and posterior lumbar muscles during trunk flexion–extension performed from two different initial positions. Trunk flexion–extension starting from either the standing or supine positions allowed for differentiation between the influences of kinematic trunk motion and the gravitational force. It is hypothesized that the two different orientations of the gravity vector will elicit two different neuromuscular responses which will reflect the different load sharing strategies and reflexive muscular responses of afferents in the viscoelastic tissues. It is anticipated that the new findings may further the understanding of the flexion–relaxation phenomena, the relative importance of the mechanical or neural processes that govern it, and its use in studying low back disorders.

2. Methods

2.1. Subjects

Thirteen male college students volunteered to participate in a protocol approved by the Institutional Review Board. The mean age, height, and body mass of the participants were 20 (±1) yr (range 18–23 yr), 178 (±6) cm (range 168–191 cm) and 82 (±11) kg (range 73–115 kg), respectively. None of the participants reported previous episodes of spinal disorders or low back pain.

2.2. Instrumentation

The surface EMG data were collected from the right lumbar paraspinous (LP), rectus abdominis (RA), external oblique (EO), rectus femoris (RF), semimembranosus (SM), and biceps femoris (BF) muscles. Electrodes on the LP were placed at the L3–L4 level, 3.0 cm lateral from the spinous processes. We collected EMG activity of the RA and EO at 3.0 cm and 15 cm lateral from the umbilicus, respectively, RF at 25 cm inferior from the right anterior superior iliac spine, SM at 25 cm superior from the medial femoral epicondyl and BF at 25 cm superior to the lateral femoral epicondyl. EMG data were collected using MA-310 (Motion Lab Systems, Inc., Baton Rouge, LA, USA). Pairs of pre-gelled Ag–AgCl bipolar electrodes 1.0 cm in diameter were
used in combination with a differential amplifier that has a gain of up to 20,000. The interelectrode distance was 2.5 cm from center to center and electrodes were oriented longitudinally along the muscle fiber length. The range of the frequency passband was set at 10–480 Hz. The common mode rejection ratio (CMRR) was 100 dB. The sampling frequency was 960 Hz. Data were collected using a 12 bit analog to digital conversion board and stored for future processing.

Kinematics of the trunk and pelvis segments were monitored by a single infrared camera (Motion Analysis Corporation, Santa Rosa, CA, USA) positioned 3.0 m away from the participant with a direct view of the participant’s left profile. The camera collected kinematic data at 60 frames per second. Reflexive spheres, 2.5 cm in diameter, were taped onto the skin on the left side at the lateral midline edge of the 12th rib, at the lateral midline of the iliac crest, and at the greater trochanter. Kinematic and EMG data were synchronized by the Eva 6.0 software of the Motion Analysis System.

2.3. Protocol

The participant’s skin was cleansed and abraded with alcohol prep pads before application of the electrode pairs to reduce skin impedance. Electrodes and markers were then placed as described above, and the signal was checked before testing to ensure quality EMG and marker detection.

The two testing conditions of trunk flexion–extension were initiated from two positions, standing and supine. Each testing session consisted of five trials of each condition performed randomly. To control for the effect of different types of footwear, participants performed each condition barefoot.

A cycle of trunk flexion–extension constituted one trial. One cycle included 5 s of controlled flexion to attain the deepest trunk flexion by touching the toes, followed by 5 s of controlled extension to the starting position. A metronome set at one auditory beat per second was used to control the tempo of the movement. Participants attempted to achieve the deepest trunk flexion on the fifth beat and the starting position on the tenth beat while maintaining a constant tempo during the cycle.

The subjects positioned their feet at shoulder width apart for each trial. During the supine condition the participants’ shoulders, pelvis, and feet were supported by three wooden platforms 3 cm in height (15 cm width). These platforms were used to prevent the EMG electrodes positioned on the low back and posterior thigh from contacting the floor. During the supine condition the legs were constrained to control counterbalance due to the movement of the trunk. A towel was placed over the distal portion of both legs, about the ankles, to provide cushioning. A wooden box (2.3 kg) containing an 11.4 kg weight was positioned over the towel to restrain lower body movement. The location of the box and the weight did not interfere with the ability of each participant to touch his toes.

2.4. Analysis

Kinematic data were tracked and smoothed by using a zero lag fourth order Butterworth digital lowpass filter with a cut-off frequency of 1 Hz. Two angles were of interest. The first angle was the lumbar flexion angle, defined as the relative angle between the line connecting the rib and iliac markers (trunk) and the line connecting the iliac and greater trochanter markers (pelvis). The second angle was the inclination angle, defined as the deviation of the trunk with respect to the vertical. The inclination angle was used to determine the relationship of body position with respect to the line of gravity.

The recorded EMG data were full-wave rectified and smoothed at 10 Hz using a fourth order zero lag Butterworth lowpass filter. The resulting linear envelopes were used for further analysis.

The resulting EMG linear envelope and angles of interest were then plotted for visual inspection before further analysis. The initiation and cessation times of the EMG activity for each muscle group were then determined. The angles and times of peak flexion and peak inclination were then calculated. Kinematic data were also used to determine the beginning and ending of each cycle during a trial. Once a complete cycle was determined, its duration was normalized to a percentage of the complete cycle. This normalization allowed for a comparison of the kinematic and EMG parameters between trials and subjects.

A threshold level of 5% of the maximal linear envelope of each muscle obtained during all of the trials for both conditions was used to initially determine the beginning and the end of the myoelectric activity. A review of the raw, rectified, and smoothed EMG data was used to determine the presence of EMG activity. Raw EMG signals may have had remnants of electrocardiograph (ECG) signals that could have distorted the detection of initiation and cessation times. The linear envelope was used as a guide based on the raw signal and in no way replaced the raw signal.

All data that were normalized to a ratio of the complete flexion–extension cycle were tested for normality using a Wilk–Shapiro test. One-way analysis of variance with repeated measures was used to evaluate the results (Statistix Analysis Program). The alpha level was set at 0.05.

3. Results

Typical data and their relationship to flexion and inclination angles in standing and supine conditions are
shown in Fig. 1(A and B). No differences were observed between the two conditions in the timing of peak flexion and inclination angle attainments during the flexion–extension cycle (Table 1). The peak flexion angle was greater in the standing condition than in the supine condition \((F_{1,128} = 19.09, P < 0.0001)\). Peak inclination angles were also greater in the standing condition \((F_{1,129} = 10.37, P < 0.002\), respectively).

3.1. Standing flexion–extension

Fig. 2 shows the timing of muscle activation and cessation versus percentage of one cycle. Tables 2 and 3 provide an overview of the initiation and cessation times for each muscle group as a percentage of the flexion–extension cycle. Three of the five active muscle groups (LP, SM, and BF) were initially active at the beginning of trunk flexion. The LP myoelectric cessation occurred at 34 \((\pm 7)\%\) of the cycle during flexion and reinitiated at 57 \((\pm 7)\%\) of the cycle during extension. The myoelectric cessation of the SM and BF muscles occurred at 32 \((\pm 7)\%\) and 19 \((\pm 17)\%\) of the cycle, respectively, during flexion and both were reinitiated at 50 \((\pm 5)\%\) of the cycle during extension.

The EMG activity of the abdominal muscles, RA and EO, were detected in the flexion–extension cycle in

![Exemplar data of EMG and flexion/inclination angles during both standing (A) and supine (B) trunk flexion–extension conditions. The vertical axis on the left is the trunk angle measurements in degrees. The vertical axis on the right is the EMG amplitude in arbitrary units. The horizontal axis is the percentage of each cycle. The thick line represents the trunk flexion angle and the thin line represents the trunk inclination angle. The inclination angle was measured with reference to the vertical \((0^\circ)\). EMG data were collected from lumbar paraspinal (LP), rectus abdominis (RA), external oblique (EO), rectus femoris (RF), biceps femoris (BF), and semimembranosus (SM).](#)
about half of the participants. This activity coincided with the myoelectric silent period of the LP muscles. RA EMG activity \((n = 5)\) was initiated at 42 \((\pm 4)\)% and ceased at 54 \((\pm 5)\)% of the cycle. EO EMG activity \((n = 7)\) was initiated at 39 \((\pm 5)\)% and ceased at 57 \((\pm 7)\)% of the cycle. EMG activity of both RA and EO muscles was observed in four individuals. One individual had only RA activity and three had only EO activity detected during this time period.

There was no co-activation of back and abdominal muscles observed during the standing condition. The EMG activity of the LP muscles ceased before the initiation of either RA or EO EMG activity during flexion \((F_{1,92} = 40.44, P < 0.0001; F_{1,87} = 9.91, P < 0.003, \text{respectively})\). No significant period of time was detected between the re-initiation of LP EMG activity and cessation of either RA or EO EMG activity during extension. The EO EMG activity was initiated before the RA EMG activity \((F_{1,60} = 10.28, P < 0.003)\) and ceased after the RA EMG activity \((F_{1,60} = 4.33, P < 0.05)\).

Both abdominal muscles exhibited no co-contraction with the lower extremity muscle activities during flexion, but did exhibit observable co-contraction during extension. RA EMG activity was initiated later than the cessation of SM and BF EMG activity during flexion \((F_{1,87} = 60.15, P < 0.0001; F_{1,73} = 50.26, P < 0.0001, \text{respectively})\), but ceased later than the re-initiation of both SM and BF EMG activities during extension \((F_{1,87} = 16.30, P < 0.0002; F_{1,74} = 16.85, P < 0.0002, \text{respectively})\). Similar to RA activity, the EO EMG activity was initiated later than the cessation of SM and BF EMG activity during flexion \((F_{1,82} = 19.98, P < 0.0002; F_{1,28} = 29.65, P < 0.0001, \text{respectively})\), but ceased after the re-initiation of both SM and BF EMG activity during extension \((F_{1,82} = 32.24, P < 0.0001; F_{1,69} = 30.77, P < 0.0001, \text{respectively})\).

The coordination of the back muscle with each of the two lower extremity muscles was slightly different. During flexion, the EMG activity cessation of the LP was later than that of the BF \((F_{1,100} = 32.78, P < 0.0001)\). There was no difference observed between LP and SM cessations. During extension, the LP EMG activity was reinitiated after that of the SM and BF \((F_{1,114} = 36.24, P < 0.0001; F_{1,101} = 32.12, P < 0.0001, \text{respectively})\). RF activity was not observed during cycles in this position.

### 3.2. Supine flexion–extension

Some unexpected LP activity was observed in the supine condition. Fig. 3 shows an example of flexion and
Inclination Angle

EMG

ceased at 67 (P < 0.001). Activity of the LP muscles increased at 51 % during the deepest flexion. During extension, EMG was observed during the early part of trunk extension. This may indicate that an inhibitory neural reflexive response was present when the passive tissues (i.e., ligaments) in the lumbar region reach near-maximum elongation.

inclination angles superimposed with LP EMG during the cycle. The EMG amplitude from the LP muscles was lower in the supine condition than in the standing condition. A burst of activity was identified during trunk extension in 11 participants.

Fig. 4A and Table 4 describe the timing of EMG initiation and cessation of four muscle groups (LP, RA, EO, and RF) detected during the supine condition. Fig. 4B illustrates the response of the LP muscles to gravitational loading during the supine flexion-extension when the trunk was flexed beyond vertical.

The LP EMG activity was silent during trunk flexion, even during the deepest flexion. During extension, EMG activity of the LP muscles increased at 51 (±12) % and ceased at 67 (±11) % of the cycle. The other three muscle groups served as agonists during flexion and were active from the beginning of the movement. The RA EMG activity ceased at 31 (±10) % of the cycle before the deepest flexion angle was attained and re-initiated at 74 (±6) % of the cycle. During extension, the EO EMG ceased at 54 (±11) % of the cycle, after the deepest trunk flexion, and re-initiated at 76 (±8) % of the cycle.

We examined the coordination among LP and the tested anterior muscles during this exercise. There was no significant difference between the cessation (30±12%) and re-initiation (74±7%) of RF EMG activity and that of RA activity. The LP EMG activity was initiated after the cessation of RA EMG activity (F1,94 = 80.53, P < 0.0001). LP EMG activity ceased before the re-initiation of RA EMG activity (F1,94 = 18.37, P < 0.0001). There was no significant difference between the initiation of LP EMG activity and the cessation of EO EMG activity. LP EMG activity ceased for a significant time period before the re-initiation of EO EMG activity (F1,93 = 17.03, P < 0.0002). EMG activity of the LP muscles was initiated after the cessation of RF EMG activity (F1,91 = 70.59, P < 0.0001) and ceased before the re-initiation of RF EMG activity (F1,91 = 12.49, P < 0.0007).

The coordination of the anterior muscles was different in the flexion and extension parts of the cycle. The EMG activity of the EO muscles ceased after the cessation of both RA and RF EMG activities (F1,125 = 155.91, P < 0.0001; F1,125 = 141.98, P < 0.0001, respectively). There were no differences observed between the RA, EO, and RF during the re-initiation of these muscle

Fig. 4. (A) EMG activities during supine condition as a percentage of one trunk flexion-extension cycle. The bars represent the EMG activity per muscle group, while the whiskers denote 1 standard deviation from the respective initiation and cessation. The dashed vertical line represents the mean point during the cycle at which the maximum trunk flexion angle was attained. Average EMG activity durations of lumbar paraspinal (LP, N = 11), rectus abdominus (RA, N = 13), external oblique (EO, N = 13), and rectus femoris (RF, N = 13) muscles during supine trunk flexion-extension. (B) Average EMG activity durations of the same muscles as in A, dependent upon the inclination angle (x-axis) during the trunk flexion-extension movement. The dashed vertical line represents the mean inclination angle. Vertical lines highlight the inclination angles at 0°, while the shaded bars represent 1 standard deviation from which 0° of inclination was attained.

Fig. 3. Exemplar lumbar paraspinal EMG pattern during trunk flexion-extension performed during the supine condition. The thin line along the x-axis is the profile of the rectified and smoothed EMG signal, which was detected at low amplitude, and denoted as a percentage of the peak EMG activity observed in the same muscle group during the standing condition. The thick line represents the relative trunk flexion angle. The dashed line represents the inclination angle of the trunk and the load applied to the posterior lumbar tissues due to gravity. Note that the greatest gravitational load in the lower in the supine condition than in the standing condition. A burst of activity was identified during the early part of trunk extension. This may indicate that an inhibitory neural reflexive response was present when the passive tissues (i.e., ligaments) in the lumbar region reach near-maximum elongation.

% EMG

LP

RA

EO

RF

Percentage of Cycle

LP

RA

EO

RF

Inclination Angle (degrees)

-90

0

0

90

-90

-80

-40

80

120

0

20

40

60

80

100

0

20

40

60

80

100

LP

RA

EO

RF

Peak

0

Trunk Angle (degrees)

Vertical lines highlight the inclination angles at 0, 20, 40, 60, 80, 100, 120, 140, and 180° of the cycle. The dashed vertical line represents the mean inclination angle (x-axis) during the trunk flexion-extension movement. The dashed vertical line represents the mean point during the cycle at which the maximum trunk flexion angle was attained. Average EMG activity durations of lumbar paraspinal (LP, N = 11), rectus abdominus (RA, N = 13), external oblique (EO, N = 13), and rectus femoris (RF, N = 13) muscles during supine trunk flexion-extension. (B) Average EMG activity durations of the same muscles as in A, dependent upon the inclination angle (x-axis) during the trunk flexion-extension movement. The dashed vertical line represents the mean inclination angle. Vertical lines highlight the inclination angles at 0°, while the shaded bars represent 1 standard deviation from which 0° of inclination was attained.
The time of cessation and re-initiation is indicative of the sequence in the cycle. Note: The back muscle activity in this condition was too low to be detected systematically, thus the EMG activity during extension is reported.

Groups during trunk extension. BF and SM activity was not observed during the supine condition.

4. Discussion

The major results of this investigation consist of the observation that 90° change in the lumbar flexion orientation with respect to the gravity vector resulted in the disappearance of the FRP in the LP muscles. An activation pattern resembling the FRP appeared in the abdominal muscles during flexion from the supine position. It was also confirmed that the abdominal muscles are active during the silent period of the FRP in the standing position. Furthermore, the thigh musculature are an integral part of lumbar flexion changing their activity with respect to the gravity vector as well.

Lumbar kinematics during anterior flexion from the standing position or the supine position are very similar. There may be some minor variation in the pelvic motion between the two conditions, but the lumbar motion is nearly identical. Therefore, if the lumbar kinematics did not change appreciably and the muscle activation pattern changed, one is to conclude that the kinematics is not a dominant factor in the muscle activation pattern. It should be noted that lumbar kinematics is closely linked with the posterior passive tissues strain and tension.

Lumbar flexion performed from the standing position or from the supine position (e.g. sit-up) will have similar impact on stretching the posterior ligaments and in turn the development of strain and the associated tension. In turn, the tension and strain are expected to stimulate mechanoreceptors within the ligaments and reflexively initiate or inhibit muscular activity. Superficially, therefore, one should expect a similar FRP response to flexion in the LP muscles from the standing and supine position. This, however, did not happen, leading the explanation to additional factors other than a simple, hardwired motor control program based on direct ligament–muscular reflexive control.

A change in the gravity vector orientation gives rise to several other factors that may impact the FRP. The vestibular apparatus is certainly engaged and responds differently, modifying neural inputs and in turn, muscular activity. Direct influence of motor and reflexive spinal control by the descending vestibulospinal tract is well-documented. Therefore a vestibular input could be considered as a major factor in the muscle activation pattern of the two conditions.

Furthermore, during flexion from the standing position, mechanoreceptors in the posterior ligaments signal the LP muscles to oppose the moments generated by the effect of gravity on the upper torso mass until ligament elongation and associated tension reaches balance with the anterior moments. At that angle, the mechanoreceptors inhibit the posterior muscles activity and further flexion requires activation of abdominal muscles. This was confirmed in this study. It is noted that the ligaments, anterior and posterior muscles as well as reflexive feedback responded to the moment requirements dictated by gravity.

In the supine position, the abdominal muscles must generate force to oppose the moment created by the effect of gravity on the upper torso mass. While the posterior ligaments are stretching and developing tension, their mechanoreceptors inhibit the posterior muscles from generating any further resistance to flexion and possibly excite the abdominal musculature to generate additional force to overcome the tension developing in the ligaments. Sharp reduction in abdominal muscle activity is evident near the vertical trunk angles (deep flexion) as the effect of gravity on the upper torso mass diminishes. While it is evident that various mechanoreceptors are engaged in fine coordination (e.g. from ligaments, facet joint capsules, discs, fascia, vestibular, etc.) the dominant factor dictating the motor control program in the two flexion positions emerges to be the moments developed by the effect of gravity and its orientation with respect to the upper body mass.

Overall, we can conclude that while the lumbar–pelvic kinematic and the ligamento–muscular/reflex programs are spatio-temporal factors continuously active in the regulation of muscle force and patterns of activation, it is the gravitational moments that determine the motor control requirements to accomplish the desired movement and the activation pattern known as the FRP. It was observed in the abdominal muscles as well in flexion from the supine position.
Force generated by the lengthening of passive tissue has been suggested to elicit the myoelectric silent period of the LP muscles during trunk flexion in the standing position. The mechanical load sharing hypothesis of the flexion–relaxation phenomenon (Allen, 1948; Floyd and Silver, 1955; Golding, 1952) usually discusses muscle activities of the posterior lumbar region. The observed abdominal muscle activity during the deepest flexion from the standing condition adds one more structure for mechanical load sharing. On the other hand, the neural hypothesis of the flexion–relaxation phenomenon (Floyd and Silver, 1951) suggests that the elongated lumbar posterior passive tissues might trigger an inhibition response responsible for inactivity of the paraspinal muscle during deep flexion. Elevated amplitude of the paraspinal muscle activity during the first one-third of the extension motion in the supine position raises questions if elongated posterior passive tissue would induce muscle activity inhibition in a direct reflexive manner. Most likely a large-scale integration of various sensory inputs takes place to accomplish such complex tasks in various positions. It is also important to note that the load sharing concept was not active during flexion from the supine position where abdominal muscles had to generate extra force to overcome the tension in the posterior ligaments.

Few studies of the flexion–relaxation phenomenon have identified abdominal activity during deep trunk flexion (Allen, 1948; Andersson, 1997; Gupta, 2001). Kippers and Parker (1984) suggested that heightened activation of the abdominal muscles is necessary to overcome posterior tissue resistance during deep trunk flexion. The abdominal muscles are required to assist gravity during flexion and serve as antagonists to the posterior tissues. In the supine position, the abdominal muscles have to overcome posterior passive tissues resistance throughout the flexion.

Timing of the LP and EO muscle activity patterns during the supine condition indicates a modulation between protagonist muscle groups when gravitational load orientation is altered between flexion and extension. The EO muscles may have served multiple roles in initial trunk flexion and support of the vertebral joints when peak trunk inclination was attained. Gradually, the gravitational load applied to the lumbar region increased and climaxed at peak trunk inclination, myoelectric silence was maintained in the LP muscles. In early extension, however, elevated LP muscle activity was observed and activity was maintained during the first third of the extension when the responsibility of maintaining the gravitational load shifted from posterior to anterior tissues. Independent of the kinematics, therefore, gravitational load orientation significantly influenced the behavior of the LP muscles (Fig. 5).

Sensory receptors, such as mechanoreceptors and vestibular sensors, respond to changes in the position of the trunk (Ross and Thewissen, 1987; Suzuki, et al., 1985). Mechanoreceptors may influence the behavior of the LP muscles during trunk flexion by transmitting afferent signals to the central nervous system (Solomonow et al., 1999). Previous investigations observed that mechanoreceptor afferents located within the passive tissues responded to changing mechanical properties of the tissues (Gray and Matthews, 1951; Grigg and Hoffman, 1982; Grigg et al., 1986; Krogsgaard, et al., 2002; Lundberg, et al., 1978). Deformation and tension within the passive tissues are dependent upon the lumbar kinematics and the magnitude of the load imparted on the system. The lumbar kinematics being similar in the standing and supine position, leaves the loads imparted on the system as the controlling input to the motor control. Thus gravity direction emerges as a crucial factor in determining the response of the overall sensory receptors output to the mechanical changes within the tissues.

This leaves the question of the ability of sensory receptors to generate excitatory outputs to muscles in one condition and inhibitory outputs in another condition while the tissue kinematics remain the same (such as lumbar kinematics in flexion from standing and supine). Recent evidence by Krogsgaard et al. (2002) demonstrated that the reflex activation of the hamstrings by receptors in the anterior cruciate ligament of human subjects was inhibited during simple walking but was present in other, more challenging conditions to the tissues. Since muscular activation is based on multiple inputs from direct activation (descending cortical inputs) and several spinal reflexive sensory activation (ligaments, joints, tendon and muscle receptors), one
can conclude that large-scale integration of such inputs takes place and could be easily modified by a single change in the activity of one set of receptors. One can expect that changes in vestibular response in the supine position, for example, may take priority in eliminating the FRP of the LP muscles while triggering a similar activation pattern in the abdominal muscles.

A secondary observation detected from the EMG data during the standing condition involved a myoelectric silent period of the hamstring muscles. Previous research looking into the FRP reported conflicting information regarding SM and BF activities (Gupta, 2001; McGorry et al., 2001; Portnoy and Morin, 1956). Fischer and Houtz (1968) and Sihvonen (1997) documented the myoelectric silent period of the hamstring muscles during studies of the trunk and hip extensors. It is essential to realize that the movement of the trunk is mechanically associated with that of the pelvis. The lumbo–pelvic rhythm is critical when explaining the interaction between trunk and pelvic movements (Esola et al., 1996; McClure et al., 1997; Paquet et al., 1994; Porter and Wilkinson, 1997). The rotation of the pelvis about the hip joint allows for further flexion of the trunk segment after full lumbar flexion is achieved. The antagonist hamstring muscles impart an extensor moment at the hip to offset the hip flexion moment supplied by gravity.

The myoelectric silent period observed in the hamstring muscles during the standing condition may indicate the activation of the golgi tendon organ. Activation of these receptors may be a consequence of increased tension due to sagittal rotation of the pelvis. Early EMG activation of the SM and BF muscles during trunk extension provides evidence to suggest that the pelvis is displaced before the trunk extends. Initiation of the hamstring muscles activity may assist the trunk extensors during extension.

In summary, anterior lumbar flexion was performed from the standing position and from the supine position while the lumbar kinematics and posterior viscoelastic structures behavior remained nearly the same. It was found that from the supine position, the FRP diminished completely during flexion whereas a similar FRP was observed in the abdominal muscles. The results lead to the conclusions that lumbar kinematics does not impact muscular activation patterns directly. Similarly, the neurological responses of receptors in the lumbar posterior viscoelastic structure are also excluded as a major direct input to muscular activation. Since gravitational orientation with respect to the body axis changed, the associated moments developed by the upper torso mass are accepted as the major input to muscular activation. Vestibular inputs are assumed to be significant modifiers of neurological responses from posterior viscoelastic structures and other muscle and tendon receptors that monitor the development of moments and orientation while triggering the appropriate muscular activation patterns to allow the performance of the intended task.

The new findings shed light on the complex interplay of kinematics, viscoelastic tissues and their neurological and mechanical behavior together with gravitational orientation in the control of lumbar motion while allowing for the major role of internal moments. The new information may assist in the assessment and understanding of low back disorders while opening a new horizon for further research into spinal structures performance in various conditions.

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