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Examination of the flexion relaxation phenomenon in erector spinae muscles during short duration slumped sitting

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Abstract

Objective. The purpose of this study was to examine the myoelectric activity of the erector spinae muscles of the back in order to determine if the flexion relaxation phenomenon occurs in seated forward flexion or slumped postures.

Background. The flexion relaxation phenomenon during standing forward flexion is well documented. However, flexion relaxation in seated forward flexion has not been studied. It is possible that flexion relaxation could be linked with low back pain that some individuals experience during seated work.

Methods. Twenty-two healthy subjects (11 males, 11 females) participated in the study. Surface electromyography was used to measure the level of muscle activity at the thoracic and lumbar levels of the erector spinae muscles. An electromagnetic tracking device measured the three-dimensional movement of the lumbar spine. Five trials each of standing and seated forward flexion were performed.

Results. A slumped sitting posture yielded flexion relaxation of the thoracic erector spinae muscles, whereas the lumbar erector spinae muscle group remained at relatively constant activation levels regardless of seated posture. Thoracic erector spinae silence occurred at a smaller angle of lumbar flexion during sitting than the flexion relaxation angle observed during standing flexion relaxation.

Conclusions. Since the myoelectric activity of the lumbar erector spinae did not increase, it is likely that the passive tissues of the vertebral column were loaded to support the moment at L4/L5. Ligaments contain a large number of free nerve endings which act as pain receptors and therefore could be a potential source of low back pain during seated work.

Relevance

Examination of flexion relaxation during seated postures may provide insight into the association between low back pain and seated work.

Keywords: Flexion relaxation; Sitting; Muscle; Lumbar; Posture; Spine

1. Introduction

Adoption of a flexed spine posture caused by computer and desk work has become an integral part of most working environments. While prolonged sitting has often been identified as being associated with back pain [1–3] there has been little progress in identifying the cause of this pain associated with seated postures. In fact, a recent epidemiological survey of the literature has questioned whether there is any association between low back pain and sitting [4]. The link between back pain and seated work has been attributed to the required flexed curvature of the lumbar spine [5]. The ligaments and muscles are the two most frequently proposed sources of low back pain. Given the association of back pain with seated spine postures we were driven to examine whether the flexion relaxation (FR) phenomenon occurred in seated postures which could load the passive structures, a potential source of pain.

FR was a term coined by Floyd and Silver in 1955 [6] which refers to a sudden onset of myoelectric silence in the erector spinae (ES) muscles of the back

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during standing full forward flexion. The two relaxation mechanisms that have been proposed are a shifting of the moment to the passive structures [6] or redistribution of muscle recruitment to deeper muscles not typically recorded [7]. Electromyographic (EMG) analysis has shown that when FR occurs, the lumbar ES exhibit a greater reduction in muscle activity than the thoracic ES in standing full flexion [8–12]. While many studies have documented FR in standing postures, there have been few studies that have examined this phenomenon in seated spine postures. Andersson et al. [7] did not directly examine FR in seated postures but a comparison of two static seated postures (erect and relaxed kyphotic) revealed that the quadratus lumborum, iliocostalis, and multifidus all showed reduced levels in the relaxed seated position.

While there has been no direct epidemiological studies to confirm the relation between low back pain and sitting [4], tissue loading scenarios that occur in seated postures have been shown to be related to the reporting of pain. Prolonged low level muscle activation has been associated with the reporting of muscle pain [13–16]. These low level contractions can impair oxygen transport in the muscle at levels as low as 2% maximum voluntary contraction (MVC) [17] which could be a source of the pain and injury associated with prolonged contractions. In an examination of prolonged seated computer work Callaghan and McGill [18] found that all subjects exhibited muscle rest levels (probability greater than zero of having EMG levels less than 2–5% MVC) in the amplitude probability distribution function of the upper and lower ES. In a comparison of low back pain and pain free individuals Salewytsch and Callaghan [19,20] found no difference in the rest gaps or average activation levels for the extensor musculature during 2 h of seated computer work.

Andersson et al. [21] used lateral radiographs of the entire spine to document rotational changes that occurred when posture was changed from standing to sitting. When changing posture from standing to sitting the lumbar curve flexed by 38° with the L4/L5 and L5/S1 motion segments having the greatest average relative changes of 10° each [21]. The in vivo analysis of the relative range of flexion from upright standing to full flexion of each motion segment of the lumbar spine has been investigated by two studies [22,23] with the total lumbar range of motion (RoM) reported as approximately 50–60° and the L4/L5 motion segment angular change reported in the range of 13–14.5° [22,23]. Seated lumbar spine postures have been shown to vary between 30% and 80% of the lumbar spine RoM [18]. In some cases these RoMs may not recruit the passive tissues whose contributions have been shown to remain low until half of the flexion RoM [24,25].

The primary purpose of this work was to determine whether FR occurred within the range of normally adopted seated postures. Secondary purposes were to assess the difference in lumbar spine angle between standing and seated FR and to determine if individuals who exhibit standing FR were more likely to exhibit seated FR. Additionally the ES muscle activation levels were assessed to determine if there was a similar response of the upper and lower, left and right erector groups in the two FR conditions.

2. Methods

2.1. Participants

Twenty-two healthy and active young adults (11 males and 11 females) were recruited from a university student population (Table 1). All subjects were healthy and free of any low back pain for a minimum of one year prior to the study. The study had received approval by the University of Guelph Human Subjects Committee.

2.2. Instrumentation

Disposable Medi-Trace surface EMG electrodes (Ag–AgCl) were applied to the skin in pairs bilaterally over the following muscles: thoracic ES, approximately 5 cm lateral to the T9 spinous process; and lumbar ES, approximately 3 cm lateral to the L3 spinous process. In order to normalize the EMG data, participants performed a MVC of the ES muscles prior to data collection [26,27]. A resting EMG level was also recorded with the subject lying prone. The EMG signals were differentially amplified (common-mode rejection ratio 115 dB, input impedance 10 GΩ) (model AMT-8, Bortec, Calgary, AB, Canada) to provide ±4 V and sampled with a 12 bit ±5 V A/D system. EMG signals were bandpass filtered (10–1000 Hz) prior to digital conversion and were A/D converted at a rate of 2048 Hz.

Lumbar flexion/extension angle was measured using a 3-Space ISOTRAK (Polhemus, Colchester, VT, USA) and the output was sampled at 20.5 Hz. The electromagnetic source was strapped over the sacrum and the sensor was attached to the skin at the level of the L1 spinous process. The zero position for lumbar flexion/extension angle was taken as normal relaxed upright standing. The 3-Space and EMG signals were synced by

Table 1
Mean and (standard deviation) for the 22 subjects' anthropometrics

Subject	Age (years)	Height (m)	Mass (kg)
Female ($n = 11$)	21.9 (0.3)	1.66 (0.09)	58.3 (6.5)
Male ($n = 11$)	21.3 (1.6)	1.80 (0.06)	79.9 (8.5)

a pulse sent from the computer controlling the 3-Space, which initiated collection of the EMG signals.

2.3. Data collection and processing

Collection protocol consisted of two flexion–extension tasks; standing full forward flexion and seated forward flexion (rounding of the lumbar spine to a "slouched" seated posture) (Fig. 1). Five trials of each task were performed, each of which lasted 36 s long. The flexion–extension cycle was comprised of three different phases (Fig. 2). The subject started from upright sitting or standing and maintained that posture for 10 s (phase 1). A computer tone signaled when the subject was to begin flexion. He/she was given 3 s to achieve the desired flexed posture with an additional tone indicating when the subject should be in full flexion. The flexed posture was maintained for 10 s (phase 2) followed by another tone indicating the initiation of extension with 3 s to reach upright sitting or standing. The upright posture was held for a further 10 s (phase 3). The chair for the sitting task was a standard height adjustable office chair with the seat back removed. The chair height was adjusted for each subject such that their thighs were horizontal to the ground with the hips, knees, and ankles at angles of approximately 90°.

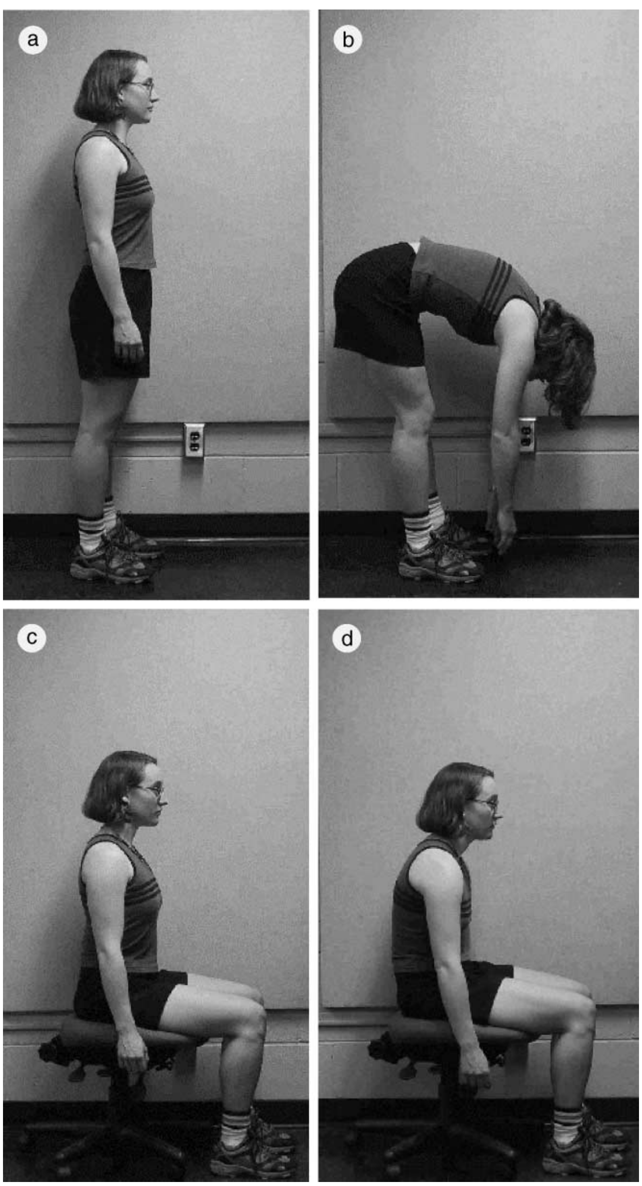

Fig. 1. Postures adopted during the flexion/extension tasks. (a) Upright standing; (b) standing full flexion; (c) upright sitting; (d) "slumped" sitting.

Processing of the raw EMG signals included digital full wave rectification followed by a Butterworth low pass filter (2.5 Hz cut-off) [28] to produce a linear envelope. The filtered signals were then normalized to the maximum muscle activity levels recorded in the MVC task and the number of samples were reduced to 20.5 Hz to align the EMG data in time with the ISOTRAK signal. Both the EMG and 3-Space signals were six-point ensemble averaged based on events identified from the 3-Space data. The six points were defined as beginning, start of flexion, end of flexion, start of extension, end of extension, and end (Fig. 2). Ensemble averaging refers to the process of normalizing a trial to 100% and aligning selected events to remove any slight timing variations that would increase variability if the signals were simply averaged. A muscle was considered to have reached FR in standing flexion if the EMG values during the FR phase were within 1% MVC of the levels during upright standing (phases 1 and 3) and resembled the EMG profile seen in Fig. 2. FR occurred in seated flexion when the EMG values during the FR phase were at least 1% MVC less than the levels during upright sitting (phases 1 and 3). The ES muscles have been shown to be more active during upright sitting when compared to upright standing [11,18,29]. Therefore FR of the muscles during slumped sitting should produce EMG levels that are lower than those during upright sitting.

2.4. Statistical analyses

Three-way analyses of variance (ANOVA) (dependent variable = gender × phase × channel, $a = 0.05$) with repeated measures on two factors (phase and channel) were used to compare the sitting and standing EMG phase data. Flexion angle data (where FR started and stopped) were compared with three-way ANOVAS (dependent variable = gender × task × channel, $a = 0.05$) with repeated measures on two measures (task and channel). Tukey's post hoc multiple comparisons were used to examine any significant findings. Only subjects who exhibited FR were included in the statistical analyses.

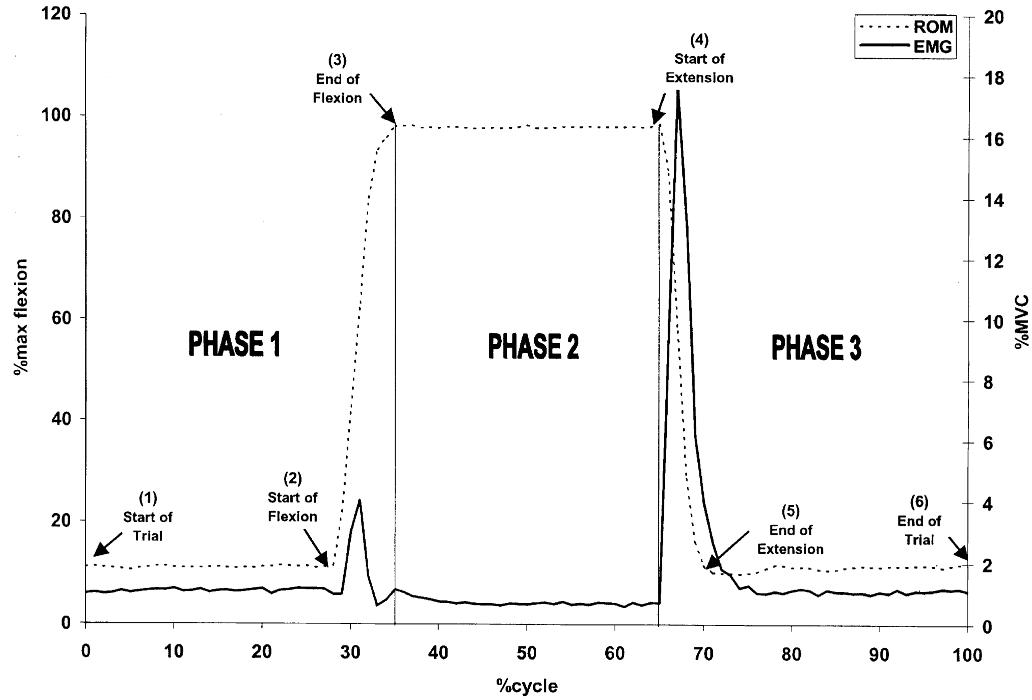

Fig. 2. Lumbar flexion and EMG for one channel illustrating the six points used to ensemble average and the three phases of the flexion–extension cycle. Data shown here is for one subject's standing trial with one channel of thoracic EMG.

Table 2
The number of subjects exhibiting FR in both standing and sitting, in only one of the two postures, or neither posture

Channel	FR in standing and sitting	FR in standing	FR in sitting	No. FR
LUES	17	1	4	0
RUES	15	1	6	0
LLES	7	11	1	3
RLES	5	13	0	4

LUES—left upper ES, RUES—right upper ES, LLES—left lower ES, RLES—right lower ES.

3. Results

Approximately 80% of all subjects exhibited FR in all muscles during standing flexion as shown in Table 2. Twenty-one out of the 22 subjects tested had FR in their thoracic ES during seated flexion. However, very few subjects demonstrated FR of the lumbar musculature in a flexed seated posture (eight left and five right lumbar ES). Subjects who exhibited FR during standing flexion tended to be more likely to exhibit FR during seated flexion.

EMG levels were compared between phases (i.e. phases 1 and 3 versus phase 2) and between thoracic and lumbar ES for subjects who were classified as exhibiting FR. During the FR phase in both sitting and standing flexion, EMG levels in all muscles dropped to a level significantly lower ($p < 0.0009$) than that of the upright phases (Figs. 3 and 4). There was no significant channel effect (i.e. left side versus right side, upper ES versus lower ES). When activation levels were examined across the 22 subjects, the lumbar ES levels remained relatively constant across the three phases (Fig. 5).

There was no significant difference in FR appearance angle between channels. In other words, all four muscles shut off (FR appeared) and came back on (FR disappeared) at approximately the same lumbar angle. FR occurred during standing flexion at an average lumbar flexion angle of 84.1% of maximum flexion and seated flexion at an average of 46.6% of maximum flexion ($p < 0.0001$) (Fig. 6). The lumbar spine was flexed on average to approximately 36% of maximum standing flexion during upright sitting (Fig. 1c) and 52% of maximum flexion in the slumped posture (Fig. 1d). After extension had been initiated, muscle activity reappeared (i.e. FR disappeared) at a greater angle ($p < 0.001$) than the point at which muscle quiescence occurred during flexion. Standing flexion had an average FR disappearance angle of 93.9% of maximum flexion, and seated flexion had an average angle of 52.8% of maximum flexion (Fig. 6). The angle of appearance of FR was significantly smaller ($p < 0.001$) than the angle of disappearance in both standing and sitting (Fig. 6). All four muscles examined demonstrated the same pattern of shutting off at a smaller angle than the angle at which activity resumed (Fig. 6). The only significant gender effect found was the interaction between gender and posture for the angle of disappearance of FR when comparing sitting versus standing lumbar spine pos-

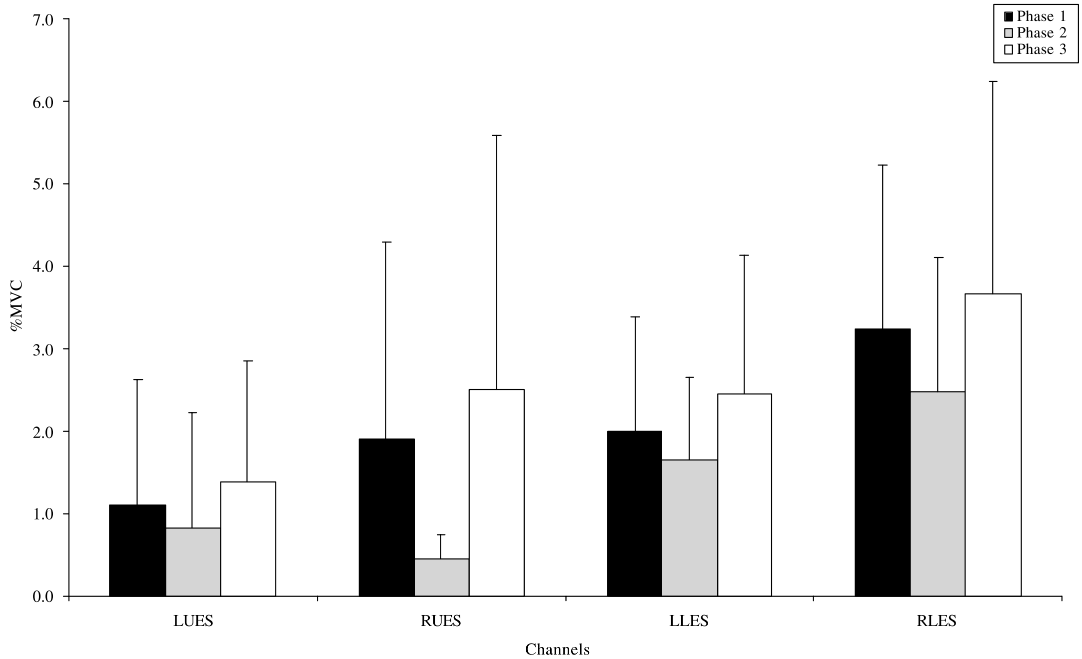

Fig. 3. EMG levels of FR (phase 2) versus upright standing (phases 1 and 3) for subjects classified as exhibiting FR (LUES—left upper ES, $n = 18$; RUES—right upper ES, $n = 16$; LLES—left lower ES, $n = 18$; RLES—right lower ES, $n = 18$).

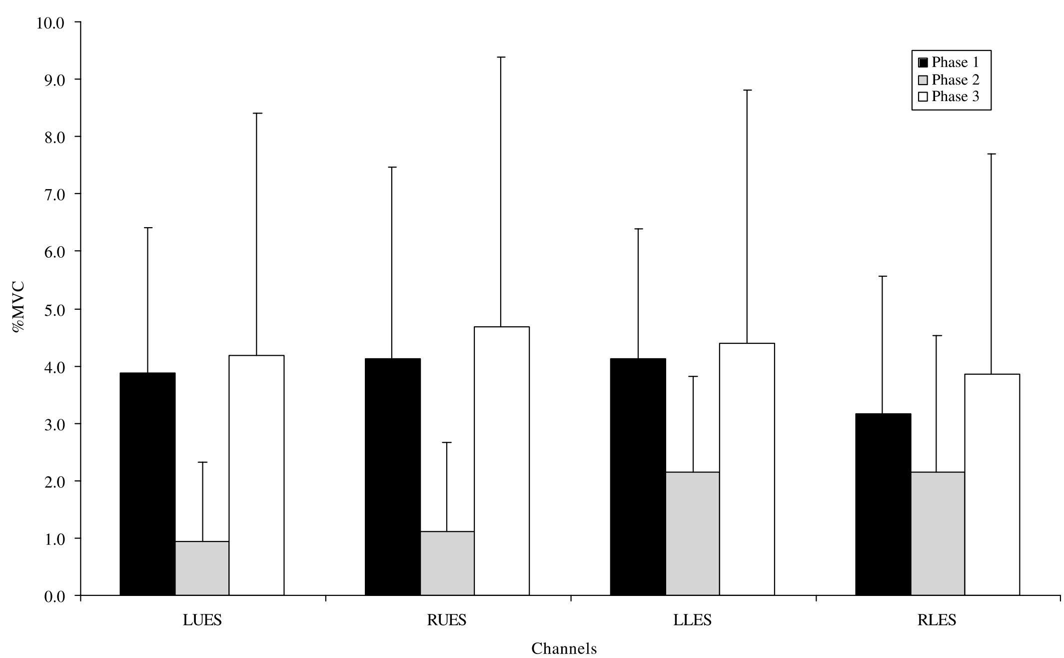

Fig. 4. EMG levels of FR (phase 2) versus upright sitting (phases 1 and 3) for subjects classified as exhibiting FR (LUES—left upper ES, $n = 21$; RUES—right upper ES, $n = 21$; LLES—left lower ES, $n = 8$; RLES—right lower ES, $n = 5$).

tures. The difference between the angle of FR disappearance in standing and sitting was larger for females than for males. In other words, females had a greater difference in the angle of FR disappearance between sitting and standing than males.

4. Discussion

A slumped sitting posture yielded FR of the thoracic ES muscles, whereas the lumbar ES muscle group remained at relatively constant activation levels across

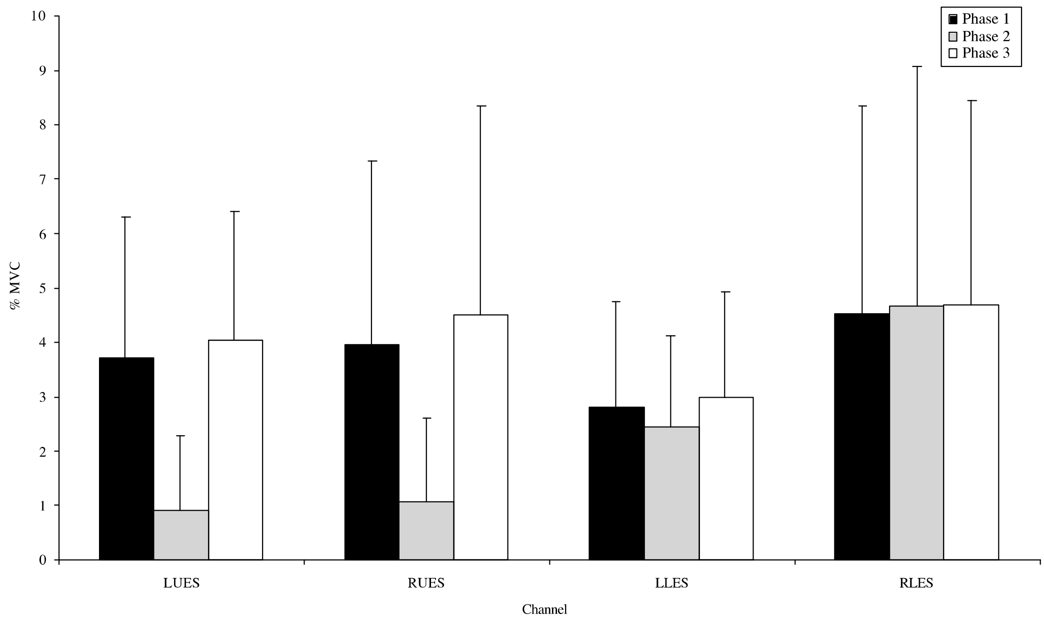

Fig. 5. EMG levels of phase 2 versus upright sitting (phases 1 and 3) for all subjects ($n = 22$) (LUES—left upper ES, RUES—right upper ES, LLES—left lower ES, RLES—right lower ES).

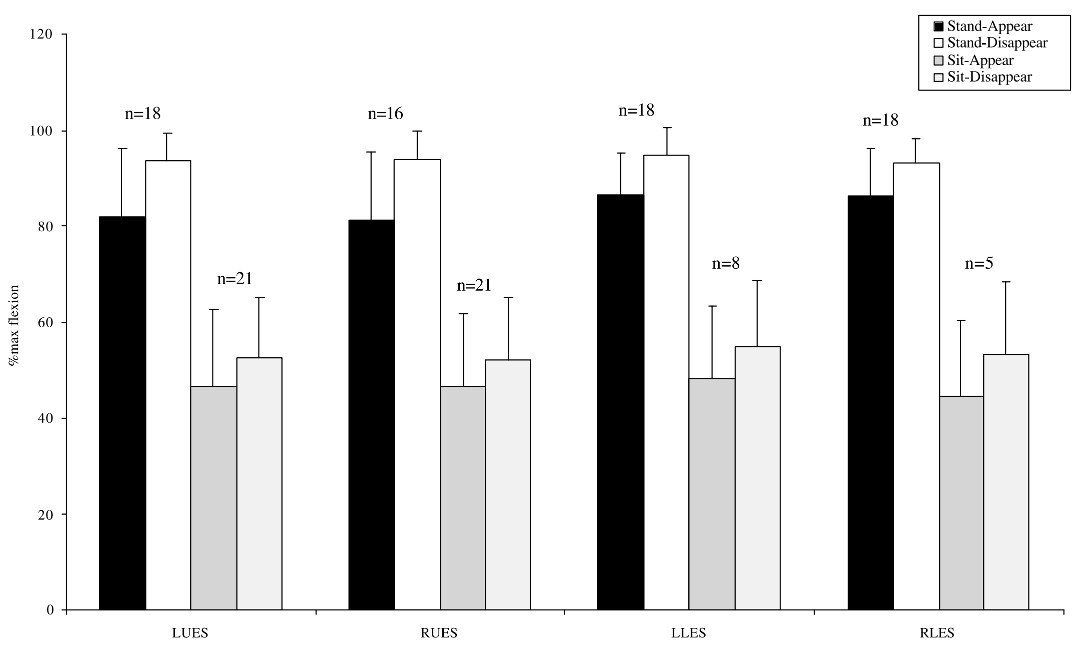

Fig. 6. RoM for the appearance and disappearance of FR during standing and seated forward flexion. The FR angle during standing versus sitting was significantly different ($p < 0.0001$) in both appearance and disappearance of FR. The angle of FR appearance is significantly lower ($p < 0.001$) than the angle of FR disappearance (LUES—left upper ES, RUES—right upper ES, LLES—left lower ES, RLES—right lower ES).

all subjects regardless of seated posture. Thoracic ES silence occurred at a smaller angle of lumbar flexion during sitting than the FR angle observed during standing FR. FR of the thoracic ES muscle group during a flexed or slumped sitting posture could explain the rest phases reported in studies, even those examining seated work in low back pain individuals.

The thoracic angle was not measured in this study, which limits knowledge about the extent to which the thoracic spine was flexed and whether the thoracic ES group was responding to changes in the lumbar spine or the thoracic spine. Since the thoracic ES (thoracic components of longissimus thoracis and iliocostalis lumborum) have been shown to cross the lumbar spine

[30] and generate moments about the L4/L5 joint [31] the response of the thoracic ES would be effected by the lumbar spine angles adopted in seated postures. Slumped sitting would likely increase the moment at the lumbar spine as the center of gravity of the upper body would be displaced anterior to the L4/L5 joint. Since there is no increase in lumbar muscle activity and a decrease in the thoracic activation levels, it is likely that the passive tissues (ligaments, lumbodorsal fascia, etc.) of the spine support the load moment. While there could be recruitment of deep muscles not monitored in this study, Andersson et al. [7] found that quadratus lumborum had negligible activation levels. The ligaments of the lumbar spine contain a large number of free nerve endings which act as pain receptors [32]. If the ligaments are loaded and must carry the load for an extended period of time, which has been shown to cause creep in the lumbar spine [33], this could stimulate the pain receptors and be a potential source of low back pain associated with seated work. Dolan et al. [34] suggested that the intervertebral ligaments do not contribute substantially to the extensor moment during FR because the lumbodorsal fascia can resist the forward bending moment when the spine is considerably (but not fully) flexed. It has been noted that there are free nerve endings found in the lumbodorsal fascia [35], which could also be stimulated during FR of the ES and be a source of low back pain.

A relatively liberal definition was used to identify the occurrence of FR. This was found to be the case in the majority of published works examined. Definitions ranged from a sudden reduction in activity [6] to a complete myoelectric silence or minimal activity of the ES muscles [7,12,36–41]. The most quantitative definition, a reduction in activity level to less than 4% MVC, was proposed by McGill and Kippers [12]. When this more stringent definition was applied to our study it identified 60% of the subjects having FR in all muscles during standing, and 84% and 20% showing the decrease of activity during sitting in the thoracic and lumbar muscles, respectively. If the more liberal criterion of reduced EMG was used, approximately 80% of all subjects showed FR during standing, and all exhibited it in the thoracic ES during sitting. These results for the percentage of tested individuals exhibiting standing FR are similar to previously reported studies [6,12,36,38, 39,41,42].

The finding of this study that FR occurred primarily in the thoracic muscles during seated forward flexion is contrary to the response in standing full flexion where the lumbar ES muscles tended to exhibit lower levels than the thoracic ES muscles [8–12]. Since the lumbar ES muscles did not demonstrate the same quiescence as the thoracic ES, this could also provide evidence for another possible mechanism, muscular, of low back pain. This lack of rest time was supported in the absence of rest gaps in the lumbar ES found in a study of a 2 h computer work period [19].

The most common theory about why FR occurs in standing flexion involves the passive tissues (ligaments, lumbodorsal fascia, etc.) being stretched to a point where they can support the moment imposed on the low back [8,41,43]. FR occurs in seated flexion at a lumbar flexion angle that is much less than standing FR. This would appear to support the mechanical idea that FR is a response to the passive tissues being able to support the imposed moment, which would be less in seated flexion and thus the passive tissues would be capable of supporting the moment at a smaller lumbar angle.

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