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Effect of individual flexibility and knee posture on the lumbar curvature and back muscle flexion-relaxation phenomenon

Yi-Lang Chen[a,b,*], Wei-Cheng Lin[a], Ying-Hua Liao[a], Chia-Jou Lin[a]

[a] Department of Industrial Engineering and Management, Ming Chi University of Technology, Taiwan
[b] Department of Industrial Design, Chang Gung University, Taiwan

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ABSTRACT

Back muscle flexion–relaxation phenomenon (FRP) studies have focused on patients with low back pain but little on individual flexibility. This study recruited 18 female participants (nine each with low and high flexibility) and analyzed the lumbar curvature and activation of the lumbar erector spinae, quadriceps, and hamstrings when the trunk flexed forward from 0° to 45°, 60°, 75°, and 90° under two knee postures (with and without the screw-home mechanism). The results show that individual flexibility significantly influenced FRP in the erector spinae during trunk forward flexion, whereas knee posture only slightly affected quadriceps activation. When trunk angle was 75° and 90°, the participants with low flexibility experienced lower erector spinae activation than did the participants with high flexibility. The participants with low flexibility also exhibited less lumbar curvature (by approximately 7°) during trunk forward flexion. This study inferred that flexible participants have a larger range of motion for trunk flexion; when the trunk flexes forward to 90°, greater lumbar curvature is maintained, resulting in a lower degree of FRP.

Relevance to industry: The lumbar spine is the part most prone to injury at work and in daily life. The current results indicate that individual flexibility may be a crucial factor when considering FRP during clinical assessment and ergonomic applications (e.g., tasks with full trunk flexion).

1. Introduction

Static trunk flexion is epidemiologically considered a risk factor for low back pain (Kumar, 2001). To understand the negative effect of trunk flexion on human body, the structure and movement mechanisms of the spine during flexion must first be understood. The lumbar spine, particularly the L5/S1 intervertebral disc, is the primary part of the spine during trunk movement (Chiou et al., 1996), which also the most prone to injury at work and in daily life.

According to Chen (1999), Taiwanese people typically have a lumbar lordotic angle of 48° when standing naturally. Any deviation from this normal curvature results in higher back muscle (e.g., lumbar erector spinae, ES) activation, leading to higher compressive forces on the intervertebral discs. Chen et al. (2015) found that as the trunk flexes forward approximately 60°, the curvature of the lumbar spine shifts from lordotic to kyphotic, which may cause more ES activation and ligament tension, thus acutely increasing the load on the L5/S1 intervertebral disc. However, as the trunk flexes forward more than 60°, ES activation suddenly decreases (Gupta, 2001; Chen et al., 2015). The passive tissues, particularly the posterior spinal ligament, replace the protractor muscle in the back to balance the moment caused by trunk forward flexion, thereby enabling trunk forward flexion. This can cause injury to ligament tissues (Shin et al., 2004; Colloca and Hinrichs, 2005).

The sudden decrease in ES activation during trunk flexion is called back muscle flexion–relaxation phenomenon (FRP), which was first noted by Floyd and Silver (1951). McGill and Kippers (1994) contended that FRP causes the load to substantially shift to the lumbar spine region, including the intervertebral disc and posterior spinal ligament, resulting in discomfort and even injury to the lower back. FRP due to trunk forward flexion can be a warning for possible back injury. Shin et al. (2004) speculated that the possible mechanism of this injury is that FRP increases the ligamentous component to the extensor moment and thus increases spinal loading caused by the shorter moment arm of the ligaments relative to the muscular tissue. The ligamentous tissues also display viscoelasticity, indicating that the extensor moment provided by these tissues and the passive tissue creep could be due to prolonged or repeated exposure (Alessa and Ning, 2018). Solomonow et al. (2003) indicated that the reduced stiffness and stability of the spine caused by FRP could be related to a mechanism of back injury

* Corresponding author. Department of Industrial Engineering and Management, Ming Chi University of Technology, 84, Gungjuan Rd., Taishan Dist, New Taipei, 24301, Taiwan.
E-mail address: ylchen@mail.mcut.edu.tw (Y.-L. Chen).

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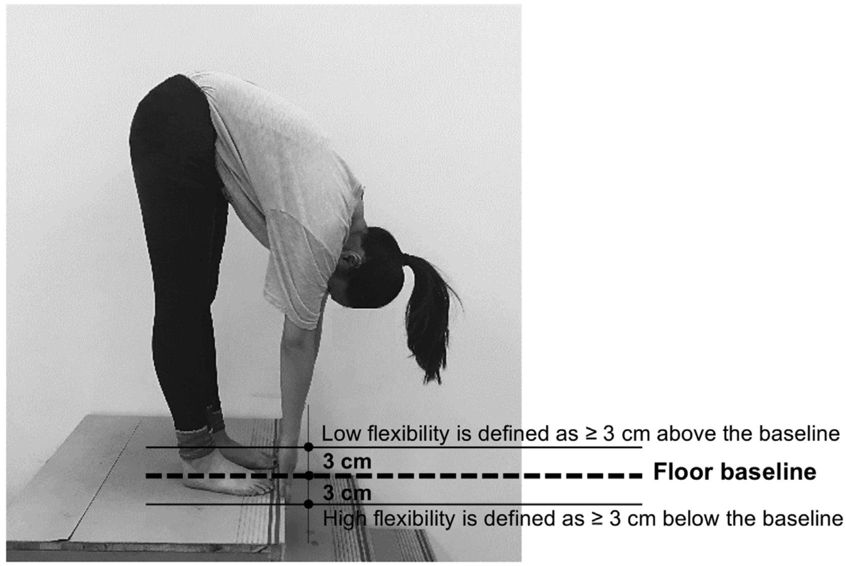

Fig. 1. Schematic of criteria for determining individual flexibility.

when individuals perform activities in fully flexed trunk positions. Although FRP may result in reduced back muscular energy consumption and fatigue (Shin et al., 2004), Colloca and Hinrichs (2005) suggested that the FRP was indicative of increased load sharing among passive structures, in which tissues have been found to fail under excessive loading conditions and shown to be a source of low back pain. Whether a movement causes FRP is a crucial indicator for measuring the safety of the movement; however, a consensus has not been reached regarding the determination of FRP occurrence. In general, decrease, rather than increase, in ES activation during trunk forward flexion indicates FRP (Shin et al., 2004). However, the onset and cession of FRP can be influenced by several factors, including lumbar posture, individual flexibility, knee position, counterweight, strength, and relative length of trunk and hip muscles (Gupta, 2001; Shin et al., 2004; Zwambag et al., 2016).

Studies have focused on FRP in patients with low back pain (Kaigle et al., 1998; Mannion et al., 2001), its biomechanical mechanism (Aratow et al., 1993), and its effects on other muscle groups (Schinkel-Ivy et al., 2014) and on the mechanism connecting the lumbar spine and pelvis (Gupta, 2001). Sihvonen (1997) reported that FRP occurred in the ES and hamstrings (HS) when the trunk flexion was 79% and 97%, respectively. In other words, when a person flexes forward from a standing posture, the ES and HS stretch, resulting in FRP; thus, the close association of the HS with a person's flexibility should be considered (Babault et al., 2014). In most FRP studies, the participants' knees are completely straight (Gupta, 2001; Shahvarpour et al., 2017); when the knees flex away from the extension position, FRP becomes less obvious (Shin et al., 2004). The screw-home mechanism (SHM) is a crucial movement mechanism that stabilizes the knee joints. According to the definition provided by Bailey (1960), the SHM exists because “the medial condyle is 1/2 in (12.7 mm) longer than the lateral condyle, which permits the femur to screw home at full extension, thereby stabilizing the joint.” Descarreaux et al. (2010) found that during trunk forward flexion, the HS and ES were strongly associated with each other, anatomically and functionally. The presence of the SHM is related to the movement of the leg muscles [i.e., HS and quadriceps (QC)], which further influence ES activation.

Studies on FRP and individual flexibility have involved small samples — only 2–3 participants for each flexibility level (Shin et al., 2004) — and SHM studies have mostly focused on knee arthroplasty and rarely examined the relationship between the SHM and FRP. Therefore, this study examined FRP caused by individual flexibility and knee SHM during trunk forward flexion in 18 female participants. We hypothesized that FRP is affected by individual flexibility and knee posture. Furthermore, participants with high flexibility may experience a lower degree of FRP than those with low flexibility when flexing their trunk to 90° from the upright position. A similar effect was expected when the participants were not in a SHM knee condition.

2. Methods

2.1. Participants

We recruited 18 female university students, aged 18–26 years. All participants were right-handed and no participant had a history of musculoskeletal injury or back pain. All participants agreed to avoid staying up late or engaging in strenuous activity throughout the experimental period. The participants were familiarized with the test procedures and paid NT$1500 for their participation. The experimental procedures were approved by the National Taiwan University in Taiwan (NTU-REC NO. 201712EM014), and all the study participants provided written consent prior to the experiment.

2.2. Flexibility test and anthropometric measurement

In the study, the participants were divided into low- and high-flexibility groups (nine in each) identified through the toe-touch flexibility test, adapted from the studies of Shin et al. (2004) and Ayala et al. (2012). The test involved a participant fully extending her knees when leaning forward and attempting to touch the floor with her fingertips (Fig. 1). The participants who touched the floor and reached 3 cm below the floor baseline were classified into the high-flexibility group, whereas those who failed to reach the floor baseline by 3 cm or more were classified into the low-flexibility group. Moreover, the anthropometric data of the participants were measured followed by the study of Chen et al. (2011).

2.3. Lumbar spine curvature measurements

We recorded the participants' spinal curvature [i.e., lumbosacral angle (LSA)] when they stood upright and flexed their trunk to 45°, 60°, 75°, and 90°; this angle was formed by the line linking the acromial shelf and the hip to the vertical. Before data collection, we attached four adhesive reflective markers to specific joints (i.e., acromial shelf, hip, knee, and ankle) and two stick markers to specific skin areas (i.e., first lumbar and first sacral spinous processes; Fig. 2). We measured