EFFECT OF FATIGUE ON ELECTOR SPINAE MUSCLES ON TRUNK POSTURAL KINEMATICS AND ELECTROMYOGRAPHYIC ACTIVITIS DURING REPETITIVE BACK SQUAT

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The aim of the present study was to demonstrate the change of the trunk posture and electromyographic (EMG) activities of elector spinae muscle and lower extremity muscles during repetitive squat motion in two different conditions with or without the back muscle fatigue task. The results demonstrated that forward trunk inclination was significantly increased during the no-fatigue condition. In addition, the forward trunk inclination appeared to be greater in the pre-fatigue condition than the non-fatigue condition. In addition, the EMG activities in the erector spinae muscles were significantly increased in the non-fatigue condition, but not in the EMG activities in the pre-fatigue condition. Appropriate muscle strength must be necessary for squat exercise to maximize the training effects and to avoid lower back injuries

KEY WORDS: lower back injury, kinematics, weight training.

INTRODUCTION: The back squat exercise is frequently implemented in strength training programs for athletic development. Due to the nature of squat biomechanics, trunk muscles, especially the erector spinae muscles, play an important role in maintaining an upright posture during the movement (Durall & Manske, 2005). The spine erector muscles have low mechanical efficiency because the moment arm of these muscles in the sagittal plane is much shorter than the horizontal distance between the lifted weight and the lower back. Consequently, the erector spinae muscles must exert a force much greater than the lifted weight to perform the squat exercise in proper posture. The resulting muscle fatigue or weakness of the erector spinae muscles can increase the risk of lower back injuries.
Forward inclination of the trunk during the back squat exercise will also increase the amount of the force imposed on the lower lumbar discs. Previous studies reported that repetitive lifting motion increased forward trunk inclination (Trafimow et al, 1993; Schoenfeld et al. 2010). In addition, a recent study also reported that the forward trunk inclination increased by means of a single set of repetitive back squats. The forward leaning posture that occurs during the back squat exercise may be related to the condition of the erector spinae muscles; however, the relationship between the postural change during repetitive back squat exercises and muscle fatigue of the erector spinae muscles remains to be elucidated.
Therefore, the purpose of the present study was to demonstrate the changes in posture in the sagittal plane and electromyographic (EMG) activities of the erector spinae and lower extremity muscles during repetitive back squat exercises under different fatigue conditions of the erector spinae muscles.

METHODS: Eight healthy male college students volunteered to participate in the study. All participants had been exercising regularly for at least the previous six months and had no history of significant injuries to their trunk or lower extremities. The average (range) age, height, and weight were 21.3 (21–22) years, 1.73 (1.68–1.82) m, and 70.9 (62.0–84.2) kg, respectively. The study protocol was approved by the Ethics committee of Ryotokuji University.
The one repetition maximum (1RM) weight for the back squat exercise was determined one week before the testing day. The test protocol included two sessions of repetitive squat motion using a weight equivalent to 75% of the 1RM weight in a pre-fatigue or no-fatigue

condition. The two different test sessions were assigned to the participants randomly and conducted at a 1-week interval.
For kinematic analysis, four self-emitting markers were attached to the outer end of the barbell shaft, the greater trochanter, the knee, and the lateral malleoli on the right side. In addition, for EMG data acquisition, we attached two surface electrodes on both sides of the vastus lateralis, biceps femoris, and thoracic and lumbar erector spinae muscles on areas of the skin prepared using a standard procedure.
During the squat task, the participants maintained an upright posture with the barbell placed on their back shoulder as the starting position. Upon receiving the verbal cue, they began lowering their body until the knee joints became parallel to the floor and then ascended immediately to the starting position. They were also required to complete each squatting motion within 6 s as set by a metronome.
In the pre-fatigue condition, the participants performed the isometric back extension task before the repetitive squatting. As the squat task, the participants were instructed to perform the Sorensen trunk holding test (Sorensen et al, 1984) holding a 20-kgf(198N) plate to their chest for 30 s. After a 30-s rest, they repeatedly performed the task until they were no longer able to maintain straight posture.
The motion data for the squat task were collected with a digital video camera (30 Hz) placed to offer a perpendicular view of the participant's right side. The two-dimensional coordinates of the attached markers were calculated using 2D–3D motion analysis software (Kinetracer, Kissei Comtec CO, LTD., Matsumoto, Nagano, Japan). We then computed the knee flexion and trunk inclination angles in the sagittal plane. For further analysis of the kinematic data, we only used the trunk inclination angle at the knee flexion angle of 60° and at the peak knee flexion angle during the descending and ascending phases.
All EMG data were also collected at 1,000 Hz using an eight-channel Tele MyoG2 system (Noraxon U.S.A. Inc., Scottsdale, AZ, USA). For analysis of the EMG data, we first divided the squat motion into four phases from the starting position to the time when the knee flexion angle reached 60° (early descending phase), from the time when the knee flexion angle was 60° to when the body was at the lowest position (late descending phase), from the lowest position to the time when the knee flexion angle returned to 60° (early ascending phase), and from the time when the knee flexion angle was 60° to the starting position (late ascending phase). The integrated value for the EMG (iEMG) data for each muscle was calculated in each phase and normalized to the averaged iEMG during maximum voluntary contraction (MVC) of each muscle. The EMG activity during maximum voluntary isometric contraction of each muscle was obtained using the manual muscle testing procedures of Hislop & Montgomery (2013).
A paired t-test was used to compare the kinematic and iEMG data between the first three and last three repetitions of the squat task in each condition. In addition, the Bonferroni correction method was used for performing multiple comparisons. The level for significance was set at 0.05 for the kinematic data and at 0.0125 for the EMG data.

RESULTS: Figure 1 illustrates the averaged trunk and leg inclination angles between the first and last three repetitions of the squat task when the body position was the lowest and when the knee flexion angle was 60° in the ascending phase in the no-fatigue and pre-fatigue conditions. In the no-fatigue condition, significant changes in the trunk inclination angle were found when the knee angle was at 60° during the ascending phase, but not during the descending phase. In addition, no significant changes were observed at the lowest position during the squat. Finally, we found no significant differences between any angles in the pre-fatigue condition.

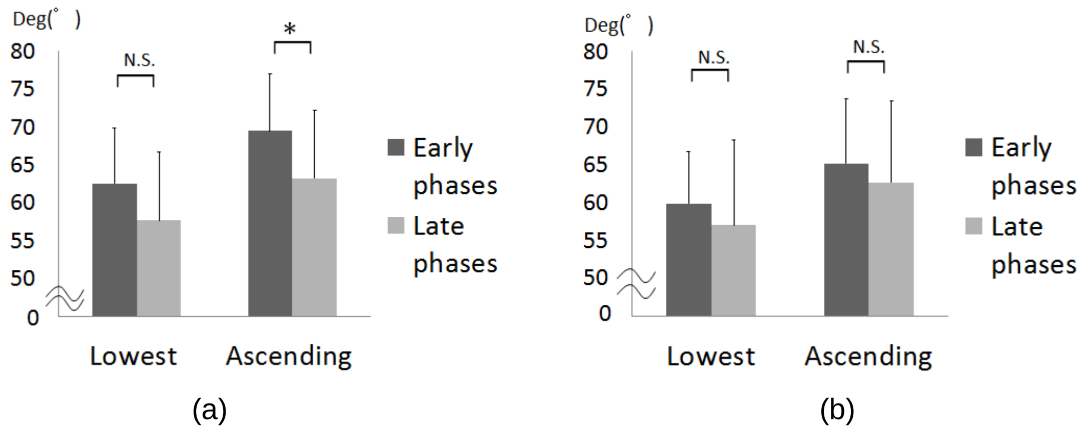

Figure 1: Trunk inclination angles between the early and the last phases of the repetitive squat task when the body position was the lowest and the ascending phase in the no-fatigue (a) and pre-fatigue conditions (b). ∗ : $p < 0.05$, N.S. : not significant

Figure 2 shows the EMG data for the erector spinae muscles, hamstrings, and quadriceps during the squat task in the no-fatigue and pre-fatigue conditions. Significant changes in neuromuscular activities in both the thoracic and lumbar erector spinae muscles were observed during the early ascending phase and in the thoracic erector spinae muscles and hamstrings during the late ascending phase between the first three and last three repetitions of the squat task. Although we found a significant difference in the hamstrings activity during the late ascending phase in the pre-fatigue condition, no significant differences were observed in the EMG activities of the erector spinae muscles and the quadriceps.

DISCUSSION: The present study demonstrated that forward trunk inclination was significantly increased during the last phase of the squat task in the no-fatigue condition. Therefore, we speculate that the moment imposed on the back may be increased during the last phase of the repetitive squat motion. Interestingly, no significant difference was observed in the trunk posture during the squat motion in the fatigued condition; however, the forward inclination angle of the trunk during the last phase of the squat task in the no-fatigue condition was similar to that in the pre-fatigue condition. Because the erector spinae muscles were already fatigued before the squat task in the pre-fatigue condition, no additional forward leaning may have occurred. The greater forward inclination increases the risk of the injury; therefore, strength and conditioning coaches may need to carefully monitor the trunk posture in the sagittal plane, particularly during the last phase of the squat movement.

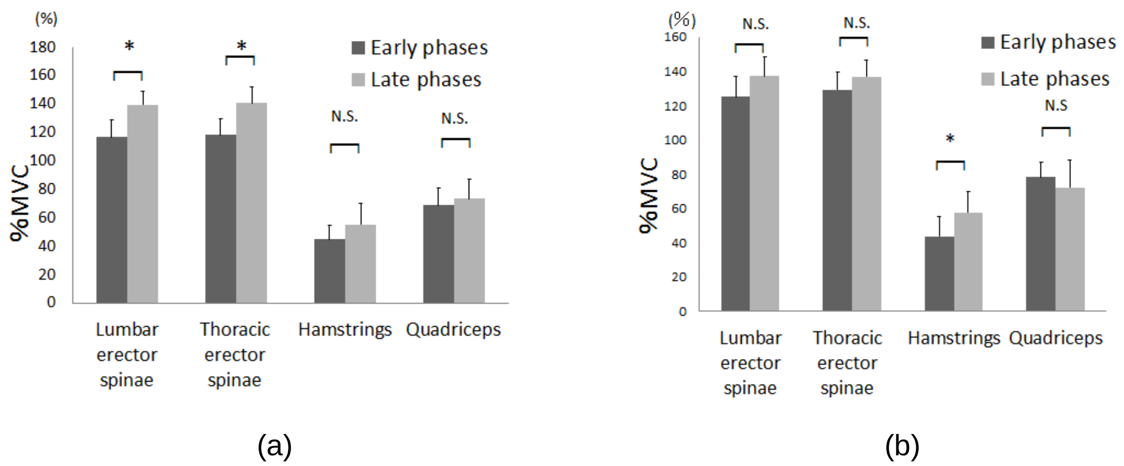

Figure 2: Average % iEMG of elector spinae, hamstrings, and quadriceps muscles during the late descending and early ascending of the squat in the no-fatigue (a) and the pre-fatigue condition (b). ＊：$p < 0.1025$, **N.S.：not significant**

The changes in EMG results showed that the activities of the erector spinae muscles and hamstrings were significantly increased in the no-fatigue condition, but quadriceps activity was not significantly increased. The motor unit recruitment increases through repetitive dynamic motion with a submaximal load to fulfil the required muscular outputs. Therefore, we speculate that the EMG change may have been related to the decrease in muscle output caused by fatigue. Trafimow et al (1993) stated that forward trunk inclination during the lifting movement can be attributed to quadriceps muscle fatigue. However, our results suggest that the forward inclination angle during the back squat movement may be directly associated with erector spinae muscle fatigue rather than the knee extension muscle fatigue. Due to the greater horizontal distance between the lifted weight and lower spine during the back squat movement, the erector spinae muscles may be required to exert a force much greater than the lifted weight to maintain posture in the back squat task. The present study also suggests that strength and endurance capacities of the erector spinae muscles may be necessary to maximize the effects of weight training and to avoid injury to the lower back during the back squat exercise.

CONCLUSION: Erector muscle fatigue may lead to anterior forward inclination during the back squat task.

REFERENCES:

Durall, C.J. & Manske, R.C. (2005). Avoiding lumbar spine injury during resistance training. *Strength & Conditioning Journal* , 27, 64-72.DOI:10.1519/00126458-200508000-00011.
Schoenfeld, B.J. (2010). Squatting kinematics and kinetics and their application to exercise performance. *Journal of strength and conditioning research*, 24(12), 3497-3506. DOI: 10. 1519/JSC.0b013e318bcb2d7.
Cappozzo, A. Selici, F. & Figura, F. (1985). Lumber spine loading during half squat exercises. Medicine and Science in Sports and Exercise, 17, 613-620. DOI: 10.1249/00005768-198510000-000016.
Trafimow, J.H. Schipplein, O.D. Novak, G.J. & Andersson, G.B. (1993). The effects of quadriceps fatigue on the technique of lifting. *Spine*, 18, 364-367. DOI: 10.1097/00007632-199303000-00011.
Sorensen, B.F. (1984) Physical measurements as risk indicqazators for low back troble over a one-year period. *Spine*, 9, 106-119. DOI: 10.1007.
Hislop, H. & Montgomery, J. (2013). Muscle Testing: Techniques of Manual Examination and Performance Testing. Philadelphia: Saunders.