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Effect of Box Height on the Muscle Activity during the Bulgarian Split Squat Exercise

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Abstract The purpose of this study was to compare the effects of box height on muscle activity of the ipsilateral erector spinae and gluteus maximus of the dominant leg during the Bulgarian split squat (BSS) exercise. A total of 21 healthy male participants were selected for this study. The participants repeated the Bulgarian split squat three times each on boxes of tibia height and half-tibia height. Surface EMG activity was recorded in the erector spinae and gluteus maximus for five seconds as the knees touched the mat and ascended during the Bulgarian split squat. Maximal voluntary isometric contraction (MVIC) calculated through the manual muscle test was used to normalize EMG activity. A paired sample t-test was conducted to evaluate the changes in the muscle activity of the erector spinae and gluteus maximus between box heights, and a p-value less than 0.05 was considered statistically significant. Although the EMG activity levels of the erector spinae and gluteus maximus were higher during BSS on a box of tibia height, the differences in muscle activity were not statistically significant ($p>0.05$). The muscle activity levels of the erector spinae and gluteus maximus were lower and similar, respectively, during Bulgarian split squat on a box of half-tibia height compared with a box of tibia height. Thus, it is recommended that BSS be conducted on boxes with shorter heights.

Keywords Bulgarian Spilt Squat, Erector Spinae, Gluteus Maximus, Box Height

1. Introduction

The squat is a widely performed exercise which builds lower body strength and induces muscle hypertrophy for athletes[1,2] as well as non-athlete individuals and is commonly prescribed for rehabilitation[3,4]. However, squats may cause pain in individuals with back and knee problems[5,6]. In addition, there are concerns over the effectiveness of the squat, a bilateral exercise, in sports that require brief temporary weight support with only a unilateral lower extremity. Thus, there are current discussions regarding whether unilateral exercises may be efficient alternatives to bilateral exercises[7,8], and various unilateral exercises have been introduced to compensate for such limitations[9].

As unilateral lower extremity exercises have closed kinetic chain characteristics and are similar to the movement patterns in our daily live, they are commonly used in muscle strengthening and rehabilitation exercises[10,11]. These unilateral lower extremity exercises can not only improve the performance of professional athletes[12,13], but also prevent injuries caused by muscle imbalance in the lower extremities. Bulgarian split squat (BSS) is a unilateral lower extremity strength exercise[14,15]. This is similar to split squat (SS) but differs in that the rear foot is supported on a stable structure behind the body. The front foot is placed at a comfortable position to balance and perform squat movements similar to those of SS[4,16]. Previous studies have suggested that BSS can cause the anterior lower extremity muscles to exert 85% of their force. This indicates that BSS may be used an alternative to the conventional squat exercise[4,7], as BSS exercise requires a higher maximum strength and power when compared to other exercises thereby also enhancing reflexes[17]. Moderate instability in BSS is the basis for neuromuscular adaptation along with increased muscle strength, and the increase in muscle strength can act as a factor to increase muscle cross-sectional area and improve neuromuscular coordination[18]. According to previous studies, squat exercise shows high muscle activity in the agonistic muscle and erector spinae (ES), whereas BSS leads to high muscle activity in the agonistic muscle and external oblique muscle[18]. In addition, BSS induces higher muscle activity in the hamstring muscle and gluteus maximus (GMA) than the quadriceps[19]. Athletes who conducted BSS maintained less than 15% difference in the muscular strength of the two legs and showed improved sprint time[20]. BSS is thought to minimize the negative effects of the difference in power and speed on acceleration between the balanced legs during sprints[21,22]. Various kinematic and EMG studies have been conducted to understand the differences in movement characteristics and activity of corresponding muscles during squat and BSS[21,23,24].

Previous studies investigated ground reaction force and joint angle according to the difference in the height of the rear foot during BSS[4]. However, to the best of our knowledge, no study has assessed the muscle activity of lower extremities after defining the box height in consideration of the subject's leg length. Therefore, the purpose of this study was to compare and analyze the effects of the different heights of the rear foot box on the muscle activities of the ES and GMA during BSS.

2. Methods

2.1. Participants

The sample size estimation was obtained using the G-power software ver. 3.1.9.7. In a pilot study on five subjects, the testing power at 0.8, effect size at 0.57, and significance level at 0.5 led to the sample size of 21. Considering a drop-out rate of 15%, the estimated sample size was n=24, and a final number of 21 participants took part in the experiment (G*power software ver. 3.1.2, University of Kiel, Kiel, Germany). The participants in this study were 24 healthy male adults who satisfied the selection criteria and had two or more years of weight training career following a previous study. All participants were given adequate explanations of the purpose and procedures of the experiment and voluntarily agreed to participate and signed the consent form. The inclusion criteria were individuals without any restriction to the hip and knee joint angles and those without neurological damage, while the exclusion criteria were individuals who had undergone surgery in the hip joint, knee joint or inguinal canal in the recent past six months, those who had an injury or pain in the lower extremity or trunk in the past six months, and those showing pain or discomfort during the experiment. Table 1 presents the general characteristics of the participants. This study was approved by the Institutional Review Board of Daegu University (1040621-202205-HR-043).

Table 1. General characteristics of the subjects (N=21)

	Mean ± SD	Range
Age(year)	24.90±3.73	20 ~ 33
Height (cm)	176.90±8.47	166 ~ 189
Weight(kg)	74.20±9.37	61 ~ 90

Mean ± standard deviation

2.2. Instruments

To estimate the muscle activity in the Erector spinae and Gluteus maximus, the surface EMG was measured using the Noraxon DTS system (Noraxon Inc, Scottsdale, AZ, USA), and the Noraxon Myo Research XP 1.06 software was used to collect and analyze the data of each muscle. The sampling rate for the EMG signals was set to 1,500 Hz.[25] The intra-rater reliability for the surface EMG was high (ICC=0.75–0.98)[26].

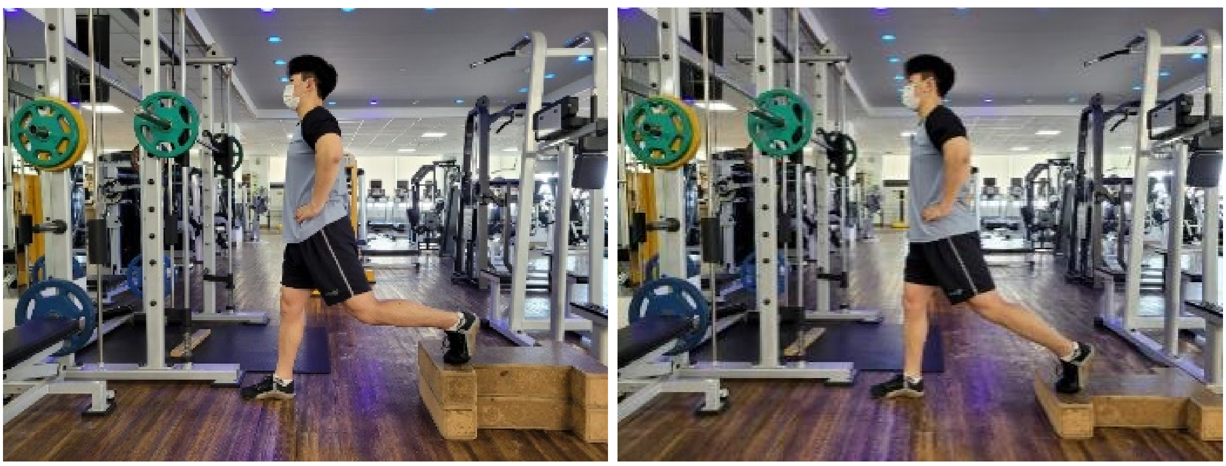
2.3. Experimental Procedures

In this cross-sectional study, participants took part in the experiment via three separate sessions. Prior to the practice in each session, the participants were instructed to perform adequate warm-up exercises of 5 min spinning cycling and 10 min dynamic stretching to ensure safety during the experiment. In the first session, the participants were given adequate explanations on the study purpose and procedures and time to practice for 30 min. After 48 hours, the second session involved 30 min practice. The third session after 48 hours involved 10 min practice and 30 min rest, after which the measurements were taken. To minimize personal judgments or bias across the participants, the box of tibia height and the box of half-tibia height were performed once and twice, respectively, in a randomized order. To assign the Box Height, the participants chose a card marked with a number between 1 and 2[27]. The measurements were taken from the foot on the lead side of the lower extremity to prevent confounding bias[28], while the leg on the lead side was set as the ball-kicking leg. To standardize the speed, a metronome set to 60 bpm (Pro Metronome app, Ver. 3.13.2; EUM Lab-Xannin Technology Gmbh., Hangzhou, CHN) was used[29]. The forward-to-back strode at 80% of the leg length from the anterior superior iliac spine (ASIS) to the medial malleolus, while the foot clearance was set to 75% of the hip width that was measured as the distance between the left and right ASIS[29]. The distance from the floor to the lateral condyle of the left tibia was measured for each participant to determine individual tibia height. The box height was set according to the individual using the box and the footstool of 1cm unit. The experiment was led by a rater and a researcher with three or more years of clinical experience in physiotherapy. The rater measured and analyzed the EMG, and the researcher controlled the participant's posture and the experimental flow. To measure muscle activities at each Box Height, an electrode was attached to a part of the participant's skin that was cleaned with an alcohol swab, shaved and scrubbed. The distance between electrodes was set to 2 cm and the surface EMG electrodes were arranged according to the recommendations in Criswell E (2010)[30].

1) (A) The participants in the box of tibia height group were guided to place the anterior leg at a position distanced from the box by the length of the leg and place the posterior foot on top of the box at the height of the tibias. With the posterior foot on the box, the upper body was slightly tilted forward, but the participants were guided not to forcefully straighten the upper body, while placing the hand on the iliac crest to maintain the upper body angle. The measurements were taken with the verbal instruction from the rater, the start of EMG measurements, and the start of metronome. The participants repeated the lowering and lifting of the posterior knee to and from the pad according to the speed three times (Fig. 1) with an adequate 3 min rest between each set.
2) (B) The participants in the box of half-tibia height group were guided to place the anterior and posterior foot as that in the box of tibia height group and proceeded in the same way. (Fig. 1)

2.4. Data Collection and Treatment

To distinguish between the eccentric and concentric phases during the movement, the phase with an increased activity of the rectus femoris muscle was defined as the concentric phase, while the muscle activity in this study was measured only during the concentric phase. As the concentric phase was repeated, the peak EMG values of the ipsilateral erector spinae and gluteus maximus muscles were identified, and the mean peak values were used for 1 sec.[10] Using the manual muscle test of the erector spinae and gluteus maximus muscles, as suggested by Kendall et al. (2005),[31] the muscle activity was analyzed at maximal voluntary isometric contraction (MVIC) and the %MVIC was analyzed for the muscle activity according to the movement being measured. For muscle strength, the mean values were obtained by measuring the maximum values thrice during the 5 sec isometric contraction in each posture. Simultaneously, the signal from each muscle was analyzed as root means square, and after excluding the first and last 1 sec from the 5 sec measurement, the mean values of the middle 3 sec were used. To minimize the muscle fatigue between the measurements, the participants were given an approximately 3 min rest.



(A) (B)

Figure 1. Measurement of muscle activity of Gma, Es according to two box height (A: box of tibia height, B: box of half-tibia height). Abbreviation; Gma: gluteus maximus, Es: erector spinae

2.5. Statistical Analysis

The data collected from the experiment were analyzed using the SPSS ver. 26 for Windows. The Shapiro-Wilk test was used to determine whether the data followed a normal distribution to approve the use of parametric techniques. To examine the change in the GMA, ES muscle activity during BSS a box of tibia height and a box of half-tibia height, the paired sample t-test was used with a significance level of .05.

3. Results

3.1. Changes in ES Muscle Activity According to Box Height

Table 2 shows the muscle activity of the ES according to the box height. High muscle activity was observed during BSS on a box of tibia height. Paired sample t-test showed no significant differences in ES muscle activity during BSS on boxes of tibia and half-tibia height ($p>.05$).

3.2. Changes in GMA Muscle Activity According to Box Height

Table 2 shows the muscle activity of the GMA according to the box height. High muscle activity was observed during BSS on a box of tibia height. Paired sample t-test showed no significant differences in GMA muscle activity during BSS on boxes of tibia and half-tibia height ($p>.05$).

4. Discussion

This study aimed to investigate the changes in ES and GMA muscle activity of the dominant leg during BSS using two boxes with different heights. EMG analysis showed that the muscle activities of the ES and GMA were higher during BSS on the taller box. On a box of tibia height, the mean muscle activity of the ES was 41% of MVIC, and on a box of half-tibia height, the mean muscle activity of the ES was 38% of MVIC. However, there was no statistically significant difference in the mean muscle activity of the ES during BSS on the two boxes. Although the 3% difference in muscle activity was not statistically significant, previous studies have reported that the increase in the speed or weight of squat linearly increases the load on the spine as well as pressure in the intervertebral disc[32,33]. Therefore, as the subject uses body weight and controls the speed of exercise, increased load and speed would lead to relatively higher ES activity on boxes of tibia height than on boxes of half-tibia height. Konrardy (2017) reported that the increase in pressure in the spine and intervertebral discs results from the additional load applied to the shoulders before squatting, and that the pressure in the spine increases during squatting as the load leans forward[4]. Therefore, during BSS, increased anterior tilt of the trunk increases hyperextension of the lumbar vertebrae, subsequently increasing the pressure in the spine and intervertebral discs as well as fatigue of the lumbar vertebral nerves[34,35].

The mean muscle activity levels of GMA were 38% and 37% of MVIC on a box of tibia height and half-tibia height, respectively. However, there was no statistically significant difference in the mean muscle activity of the GMA during BSS on the two boxes. As reported in prior studies, the position of the trunk regulates the biomechanics of the knee and hip joints in various work environments[36]. In other studies, trunk flexion was shown to increase the muscle activity of the GMA in a static standing position[37]. The anterior tilt position of the trunk lengthens the leverage between the center of gravity (COG) and hip joints. This generates more torque in the GMA than does the normal tilt position. In a previous study, Jones et al (2012) compared muscle activity of the gluteus maximus using EMG during BSS and squat and observed greater muscle activity during BSS than during squat[38]. BSS is a representative closed-chain, functional multi-joint exercise with a high mobilization rate for hip extensors[39,40]. In addition, mobilization and activation of muscles in these functional patterns may improve proprioception and coordination, subsequently reducing the risk of injuries[41,42]. Therefore, as there were no significant differences in the muscle activity of GMA using different heights of boxes, BSS on a box of half-tibia height with less burden on the erector spinae is considered ideal. As a result, to prevent injuries and protect the health of athletes and general individuals, we recommend performing BSS on a box of half-tibia height.

Table 2. Muscle activities of erector spinae and gluteus maximus in Bulgarian split squat for two box height (Unit: %MVIC)(N=21)

Muscles	BTH	BHTH	*t*	*p*
erector spinae	41.44±14.80	38.92±15.43	.493	.630
gluteus maximus	38.86±18.70	37.99±16.59	.441	.667

Abbreviation; BTH, Boxes of tibia height; BHTH, Boxes of half-tibia height

Mean ± standard deviation

Several limitations must be considered in the interpretation of our findings. First, all participants were healthy male adults without pain or disability in the hip and knee joints, who had more than two years of weight training experience and underwent three training sessions to become familiar with the exercise. Therefore, it is uncertain whether individuals without prior weight training experience will show the same level of muscle activity during BSS, especially since the level of muscle activity may vary between individuals. Second, the contribution of other muscles such as the quadriceps and hamstrings were not considered in this study. However, as the related muscles exert synergistic effects, the function of the hamstring and quadriceps must be considered and not interpreted separately. Third, this study could not accurately evaluate the muscle activity of the ES and GMA during BSS on different heights. Further studies to establish a generalized protocol that can be applied efficiently and selectively for boxes of various heights must be conducted.

5. Conclusions

This study investigated the ideal box height to increase the muscle activity of the GMA without increasing the activity of the ES during BSS in 21 healthy adults with more than two years of weight training experience. Although the difference was not statistically significant, the results showed higher activity of the ES and GMA during BSS on a box of tibia height. BSS on a box of half-tibia height can induce GMA force, similar to that observed during BSS on a box of tibia height. However, reduced anterior height leads to less burden on the lower back. Thus, it is suggested to use boxes of short height during BSS. Although this study adjusted the box height according to the individual leg length to measure muscle activities unlike in previous studies, the results were in accordance with that of previous studies. Based on the results of this study and other several important previous studies, further research should aim to develop balanced exercise regimens for lower extremity muscles that can maintain a lower level of ES activity. Furthermore, more detailed comparison of different box heights and investigation of balanced joint activation of different muscles are required.

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