EFFECT OF HEEL HEIGHTS ON LOWER EXTREMITY MUSCLE ACTIVATION FOR BACK-SQUAT PERFORMANCE

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The purpose of this current study was to investigate the effect of different heel heights on lower extremity muscle activation during back-squat performance. Eight healthy active male collegiate students with back-squat experience volunteered for the study (BH: 1.83 ± 0.09m; BM: 88.45 ± 16.46kg). Each subject performed five trials of back-squat performance in four different heel height conditions (0, 0.5, 0.75, 1 inch; 1.27, 1.91, 2.54 cm, respectively) in random order. Mean muscle activations were obtained from VM, VL, MG, and LG between onset and end of a back-squat performance at 70% of 1 RM. Results indicated that LG and MG had significantly greater mean muscle activation in 0.75- and 1-inch heel height conditions than no heel height condition ($P < 0.01$). Different heel heights had no effect on mean muscle activation at VM and VL.

KEY WORDS: EMG, repetition maximum, weight lifting

INTRODUCTION: The back-squat is a multi-joint movement used to develop neuromuscular control and strength in both athletic and rehabilitation settings to develop the posterior chain and strengthen the muscles around the joints of the lower extremities (Myer et al., 2014). Incorporating the back-squat into a training program will improve athletic performance by enhancing leg, hip, and back strength (Robbins, Marshall, & McEwen, 2012). The effect of back-squat training on sports performance has been extensively studied (e.g., Hoyo et al, 2016; Styles et al, 2015) and factors that influence back-squat performance such as footwear types have also been examined (Whitting, Meir, Crowley-McHattan, Zachary, Holding, 2016; Sato, Fortenbaugh, & Hydock, 2012, 2013). While the significant effects were found due to footwear types, the influence of different heel heights on back-squat performance has yet to be examined in detail.
Barefoot squatting or the use of weightlifting shoes has been adopted in strength and conditioning regimens due to the benefit of a rigid surface. Studies found that rigid surfaces provide more stable support which enhances force generation with better squatting technique (Sato, Fortenbaugh, & Hydock, 2012, 2013; Shorter, Lake, Smith, & Lauder, 2011). As for muscle activation, only one study examined the lower extremity EMG difference among the footwear types and found that rectus femoris had greater peak and mean muscle activation in running shoe and barefoot squatting conditions (Sinclair, McCarthy, Bentley, Hurst, & Atkins, 2015). During a simple deep squat movement, Sriwarno, Shimomura, Iwanaga, and Katsuura (2008) found greater muscle activation at gastrocnemius in tip-toe squatting condition. Other studies have demonstrated the benefits of weightlifting shoes when compared to regular athletic shoes.
Very few studies have investigated the effect of heel heights on squat performance. One study conducted by Edwards, Dixon, Kent, Hodgson, and Whittaker (2008) found that as the heel height increases, the mean muscle activation at vastus medialis and lateralis increases during sit to stand movements in young women. There is limited understanding of how different heel heights influence the squatting performance. Therefore, the aim of this current study was to examine the effect of four different heel heights (0-, 0.5-, 0.75-, and 1-inch) on lower extremity muscle activation. Additionally, in an attempt to provide more insights of the benefit of raised heel height on squatting performance or rehabilitation purposes.

METHODS: Eight healthy and active male collegiate students (Age: 21.5 ± 1.87 years old; Body Height: 1.83 ± 0.09m; Body Mass: 88.45 ± 16.46kg) volunteered from the local university. All the subjects had experience with back-squat performance and knowledge of their one-repetition maximum weight measured through the course required from the major.

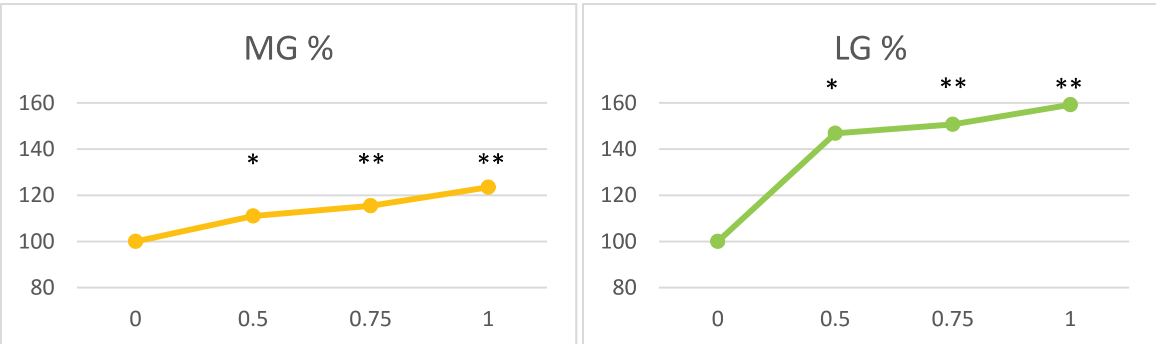
No injury within the past six months was reported by any subject. All policies and procedures for the use of human subjects were followed and approved by the university's Institutional Review Board.

Each subject was required to complete a series of dynamic warm-up prior to data collection. A total of four different heel heights conditions in inches were performed in a random order, 0-, 0.5-, 0.75-, and 1-inch (2.54 cm). All the subjects were required to perform five trials of back-squat with 70% of their one-repetition maximum weight at each height. Each trial was a full cycle of a back-squat performance including downward and upward phases to be completed within 4 seconds in a consistent pace. The end of downward phase was determined when the thigh segment was parallel to the floor. Three pairs of wooden wedges with a dimension of three inches wide and six inches long in each height were used to control the height of the heels. All the trials were performed bare foot. After data collection, the preference of the heel height condition was surveyed from each participant.

Muscle activation was obtained through electromyography (EMG) of vastus lateralis (VL), vastus medialis (VM), lateral gastrocnemius (LG), and medial gastrocnemius (MG) of the right leg. The electrode sites were determined according to the procedure outlined by Rainoldi, Melchiorri, and Caruso (2004). The areas were primed by removing dead skin and hair with a shaver and alcohol wipe. The disposable AG/AgCl dual electrodes (Noraxon, Scottsdale, AZ, USA) in conjunction with a wireless DTS system were used to obtain the EMG signal. The EMG data was sampled at the rate of 1000 Hz and filtered with bandpass at 10-450 Hz first, rectified, and integrated with moving window of 50 milliseconds. Muscle activity was determined by averaging the whole cycle of the movement (MEMG) from onset to the end of the movement.

Repeated measurement ANOVA was performed to determine the muscle activation difference among four conditions (SPSS 22). Greenhouse-Geiser corrections were used if the assumption of sphercity was violated. Bonferroni-Holm's correction was applied to perform pair-wise comparison. Since there were multiple comparisons, to lower the chances of type I error, all the statistical significance was set at $P < 0.01$. All the muscle activations were also normalized to the control condition (0-inch heel height) to determine the percentage difference.

RESULTS: Repeated measurement ANOVA showed significant difference of muscle activation due to the height of heel in both MG and LG. Both 0.75- and 1-inch heel height conditions had significant greater mean muscle activation than 0-inch condition with $P < 0.01$. Although the increases of mean muscle activation for both VL and VM were observed due to heel heights, there was no statistical difference with $P > 0.05$. Figure 1 shows the difference of mean muscle activation in percentage of the control condition. Seven out of eight participants preferred heel being raised (4 in 1-inch, 2 in 0.75-inch, and one in 0.5-inch) and only one preferred barefoot condition.



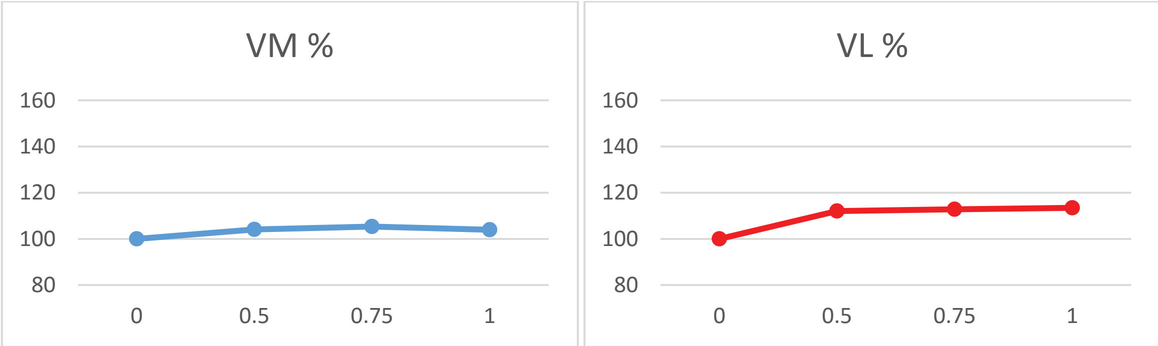


Figure 1. Mean muscle activation in percentage of no heel height condition. ** represents significant difference from no heel height condition with *P* < 0.01 and * represents the significant difference from no heel height condition with *P* < 0.05.

DISCUSSION: The major finding of this current study was that mean muscle activation was significantly higher at MG and LG in 0.75- and 1-inch conditions when compared to no raised heel height ($P < 0.01$). The difference was about 12 to 60% among four different heel heights. This finding supports the results of Sriwarno et al. (2008) who reported that peak gastrocnemius activation was increased as the heel height increases during a deep squat movement. This enhancement of average muscle activation at gastrocnemius was expected to stabilize the ankle joint due to the elevation of the heels. The elevation of heels may shift the center of mass anteriorly where gastrocnemius requires activation to control balance and stabilization during the squat performance. Although the significant difference of the mean muscle activation at gastrocnemius between 0.5 inch and 0 inch was observed ($P < 0.05$), the significance level did not meet the standards of this current study. Interestingly, when the heel height was raised to and above 0.5 inch, there was no significant difference of mean muscle activation at gastrocnemius among three heel height conditions. The findings of this current paper may be useful for rehabilitation purpose when activation of gastrocnemius is needed then 0.5-inch height is essential. Further study may be warranted to examine the difference of kinematic variables during back-squat performance with different heel heights.
Although there was a small increase of mean VM and VL activity (4 to 13%) with raised heel, the increase of muscle activity was not significant among all the conditions ($P > 0.05$). This finding supports the study (Edward et al., 2008) that examined a similar movement with four different heel heights in women and found no significant mean VM and VL activity between barefoot and heel heights that below 3 cm. The current study only raised the heel heights to 2.54 cm while Edward et al. (2008) found significant increase in VM and VL activity in 5 cm condition. Additionally, seven out of eight participants preferred to perform back-squat with heel raised. This may due to the flexibility of the triceps surae and the Achilles tendon. With the raised heel, participants felt more comfortable squatting down to the position where the thighs are parallel to the floor. There are several limitations for this current study: 1) small sample size of men, 2) subjects experience of performing back-squat movement was varied, 3) only 70% of one RM was used as resistance, 3) some of the subjects had difficulty to control the pace and compete some trials earlier than 4 second which may affect the data, and 4) the width of the stance was not controlled when it could have influence on gastrocnemius activity (Escamilla et al., 2001).

CONCLUSION: The present study found that raised heel height above 0.75-inch significantly increased the mean muscle activation at MG and LG but not VM and VL when compared to no heel raised condition. There was no significant mean muscle activation at all muscle groups examined among the three heel raised conditions. This suggests that if the purpose is to increase gastrocnemius activity, the minimum heel height would be 0.75-inch and any height above it until 1-inch would not have any further enhancement of muscle activity. Raised heel height of 0.5-, 0.75- and 1-inch had no significant effect on VM and VL activity.

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