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ORIGINAL

The Effect of Exercise Intensity on Muscle Activity and Kinematic Variables of the Lower Extremity during Squat

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Objective: The purpose of this study was to determine how exercise intensity affects muscle activity and kinematic variables during squat.

Method: Fifteen trainers with >5 years of experience were recruited. For the electromyography (EMG) measurements, four surface electrodes were attached to both sides of the lower extremity to monitor the rectus femoris (RF) and biceps femoris. Three digital camcorders were used to obtain three-dimensional kinematics of the body. Each subject performed a squat in different conditions (40% one-repetition maximum [40%1RM], 60%1RM, and 80%1RM). For each trial being analyzed, three critical instants and two phases were identified from the video recording. For each dependent variable, one-way analysis of variance with repeated measures was used to determine whether there were significant differences among the three different conditions ($p<.05$). When a significant difference was found, post hoc analyses were performed using the contrast procedure.

Results: The results showed that the average integrated EMG values of the RF were significantly greater in 80%1RM than in 40%1RM during the extension phase. The temporal parameter was significantly longer in 80%1RM than in 40%1RM and 60%1RM during the extension phase. The joint angle of the knee was significantly greater in 80%1RM than in 40%1RM at flexion. The range of motion of the knee was significantly less in 80%1RM than in 40%1RM and 60%1RM during the flexion phase and the extension phase. The angular velocity was significantly less in 80%1RM than in 40%1RM and 60%1RM during the extension phase.

Conclusion: Generally, the increase of muscle strength decreases the pace of motion based on the relation between the strength and speed of muscle. In this study, we also found that the increase of exercise intensity may contribute to the increase of the muscle activity of the RF and the running time in the extension phase during squat motion. We observed that increased exercise intensity may hinder the regulation of the range of motion and joint angle. It is suitable to perform consistent movements while controlling the proper range of motion to maximize the benefit of resistance training.

Keywords: Squat, Exercise intensity, Muscle activity, Kinematic variables

INTRODUCTION

As a result of improved living standards and increased leisure time, the levels of physical activities have significantly decreased and the incidence of diseases due to lack of exercise and physical activity has been drastically increasing. Accordingly, people have begun to pay more attention to their health, and invest time and effort to improve their quality of life through health enhancement.

Muscle strength, which is a component of health enhancement, is an essential factor for normal muscle functioning and musculoskeletal injury prevention. Effective exercise methods for muscle development include weight training, which can increase muscle strength, increase lean body mass, and reduce body fat when performed on a regular basis (Kenney, Wilmore, & Costill, 2015). Weight training, which plays an important role in health enhancement, is recognized as major muscle-strengthening exercise among modern people with lack of exercise.

Weight training is a type of resistance training for muscle development and health enhancement, and consists of weight-bearing exercises or resistance exercises with barbells, dumbbells, and exercise machines (Sprague & Reynold, 1983). To reach the goal of weight-training exercise for muscle strengthening, the appropriate exercise intensity must be applied according to an exercise prescription designed by an expert that is based on the principle of progressive loading. However, most people begin their weight training after learning how to use simple exercise machines on their own without any guidance from an expert. Inappropriate exercise-intensity settings and postures can negatively affect the musculoskeletal system and exercise outcome. Haff and Triplett (2015) and Rao, Amarantini, and Berton (2009) reported that it is difficult to accurately perform a movement or maintain a stable posture during free-weight exercises when incorrect intensity settings are used.

Among weight-training exercises, squat exercise is a major lower-extremity muscle-strengthening exercise that not only strengthens the muscles of the hip, femur, and trunk, which are important for running, jumping, and lifting, but also improves bone density, ligament strength, and tendon quality (Escamilla, 2011). Squats are commonly performed in body training and rehabilitative training, and can produce various exercise outcomes. To maximize the effects of squat exercise on muscle development or strength, appropriate exercise intensity must be used and cyclically increased (Frost, Cronin, & Newton, 2008). However, studies that have analyzed joint movements during a squat have reported that increasing the load according to the exercise intensity can negatively affect the maintenance of stable postures, and subsequently, negatively affect the exercise outcome as movements are performed in wrong postures (Chae, Jeong, & Jang, 2007; Fry, Smith, & Schilling, 2003; Park, 2011).

Fry et al. (2003), who analyzed appropriate positions and postures of the knee joints during a squat, reported that when the knee joint protrudes forward excessively at the curve or when the body slants forward, the activity of agonistic muscles decreases and the rotational force on the knee and hip joints increases. Chae et al. (2007) reported that to reduce the weight applied to the waist during squat exercise, it is important to maintain the upper body upright while performing the movement so as to minimize the shifting of the center of gravity in the forward and backward directions, and maintain a stable posture. Park et al. (2011) compared the differences in squat movements according to the level of exercise experience, and reported that the range of motion of the knee and hip joints decreased as the load was increased, and that this increase was more significant among beginners who were not used to performing squats; thus, excessive load bearing can impede performance of appropriate movements. In the case of trained subjects, the activity of the quadriceps muscle, which are agonistic muscles, increased as the load was increased. In the case of beginners, the range of motion of the joints decreased as the load was increased, which hindered the efficient use of agonistic muscles; thus, no significant difference in the quadriceps muscle activity was observed according to the load applied. On the basis of these previous findings on squat exercise, it is important to maintain appropriate postures as exercise intensity is increased to maximize the effects of squat exercise. However, criteria for appropriate postures during squat exercise are vague, and objective data on muscle activities and joint movements that can be used as the standard for movement performance are lacking.

Therefore, the present study aimed to establish criteria for appropriate squat performance by analyzing the femoral muscle activity and kinematic factors according to exercise intensity during squat exercise in professional trainers.

METHODS

1. Participants

Fifteen male trainers with >5 years of experience in exercise training were selected to perform squat exercise. The participants had a mean age of 28.5±3.9 years, mean height of 176.0±5.5 cm, mean weight of 78.5±8.3 kg, mean muscle mass of 38.2±3.5 kg, mean body mass index of 25.3±2.1 kg/m^2, and mean body fat percentage of 14.9±4.3%.

2. Experimental setup

1) Electromyography

In this study, an electromyogram (QEMG-8; Laxtha Inc., Korea; gain = 1000, input impedance $>10^{12}$ Ω, common mode rejection ratio >100 dB) was used. Four surface electrodes for measuring the electrical activity of muscles were attached to the left and right rectus femoris (RF) and biceps femoris (BF), respectively (Table 1) (U.S. Department of Health and Human Services, 1993). The ground electrode was attached to the anterior superior iliac spine. To minimize skin resistance, areas where the surface electrodes were to be attached were completely shaved and wiped with alcohol before electrode attachment. To standardize electromyogram data, the dynamic movement cycle (DMC) method was used (Yang & Winter, 1984). Each participant was asked to perform three squats at 80% one-repetition maximum (80%1RM) before the experiment to measure the maximum electromyography (EMG) value during the body movement cycle. The maximum of the three measurements was selected for each group and used as the standard value. The sampling frequency for the collection of EMG data from the movement cycle and squat exercise was set to 1,024 Hz.

Table 1. Electrode placements

Muscle	Electrode placements
RF (rectus femoris)	
BF (biceps femoris)	

2) Three-dimensional (3D) kinematics

For 3D analysis during squat exercise, three digital camcorders (60 Hz, Sony HDR-HC9) were placed in the front, to the left, and to the right of the participant (Figure 1). The shooting speed was set to 60 fields/s and the shutter speed was set to 1/725 s. To obtain the coordinates of the centers of joints, reflective markers measuring 0.8 cm in diameter were attached to the hip, knee, ankle, toe, and heel.

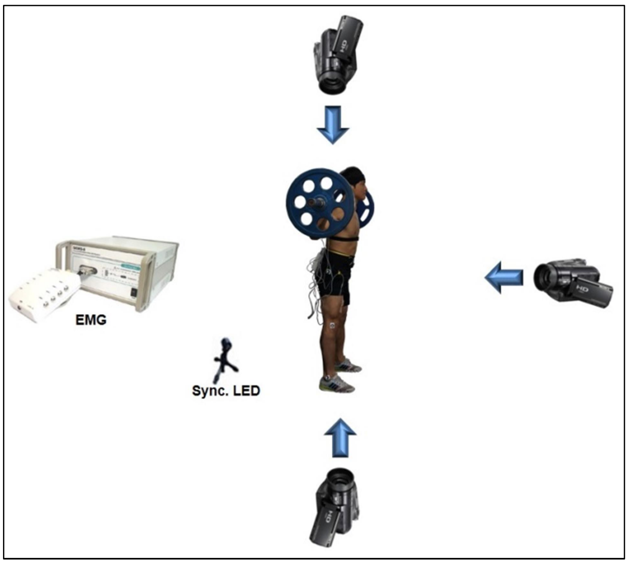

Figure 1. A view of the experimental setup

3) Sync

To synchronize EMG data and video data, a switch on a signal tuner (Visol Inc., Korea) was pressed at an arbitrary time point during the squat exercise to simultaneously initiate 5-V electrical signals in the A/D board connected to the electromyogram and two light-emitting diodes (LEDs). On the basis of the time point at which the 5-V electrical signals occurred and the LED signals became synchronized on the videos, points of view and time phases to be analyzed were determined.

3. Data collection

All participants were restricted from high-intensity physical activities that can induce fatigue, and performed warm-up exercises for 10 min before the experiment. The %1RM method, in which exercise intensity is set in terms of 1RM, was used during squat exercise. With this method, each participant's 1RM before the experiment was measured. In the experiment, each participant performed five squats each at 40%1RM, 60%1RM, and 80%1RM. Data from the five squats performed under each condition were analyzed.

4. Data analysis

1) Events and phases

In this study, the squat movement was broken down into two phases from the three points of view, as shown in (Figure 2). Extension 1 was defined as the point of maximum extension before the movement relative to the angle of the knee joint. Flexion was defined as the point of maximum flexion, and Extension 2 was defined as the point at which the participant returned to the maximum extension. From Extension 1 to Flexion was the flexion phase, and from Flexion to Extension 2 was the extension phase.

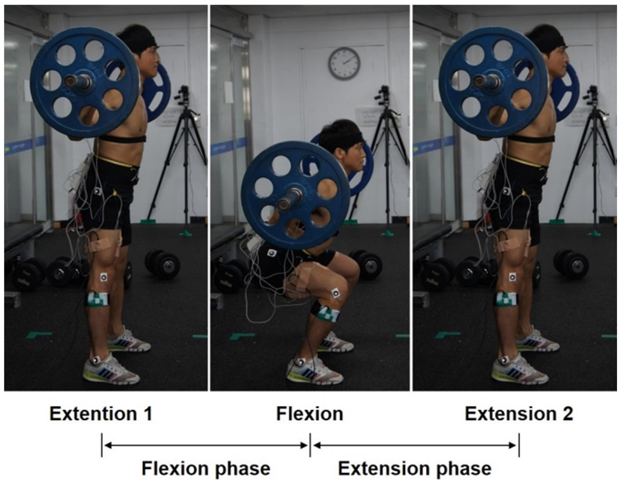

Figure 2. Critical instants and phases of treadmill walking

2) EMG

EMG data collected during squat exercise were filtered using 350-Hz low-pass filter and 10-Hz high-pass filter, and processed using a full-wave rectifier. Next, the data were standardized to maximum EMG values during a movement cycle for each muscle, by using the equation below, and integrated EMG values were calculated for each phase.

$$nEMG = \frac{EMG_{trial}}{EMG_{DMC}} \times 100$$

where $nEMG$ = standardized integrated EMG value, EMG_{trial} = EMG value of a particular phase during the movement cycle, and EMG_{DMC} = maximum EMG value during the movement cycle.

3) 3D kinematics

3D movement analysis was performed using the Kwon3D 3.1 program (Visol Inc., Korea). 3D coordinates were calculated using direct linear transformation (Abdel-Aziz & Karara, 1971). To minimize noises during the process of finding 3D coordinates, a secondary Butterworth low-pass digital filter was used, with the cutoff frequency at 6 Hz. Joint angles during the squat movement were defined as shown in (Figure 3) and were calculated through vector dot product calculation.

5. Statistical analysis

To test for statistically significant differences in the muscle activity and kinematic factors according to exercise intensity during squat exercise, SPSS 23.0 was used to perform one-way analysis of variance with repeated measures. If significant differences were found, a contrast analysis was performed as a post hoc test. The level of statistical significance was set at $p<.05$.

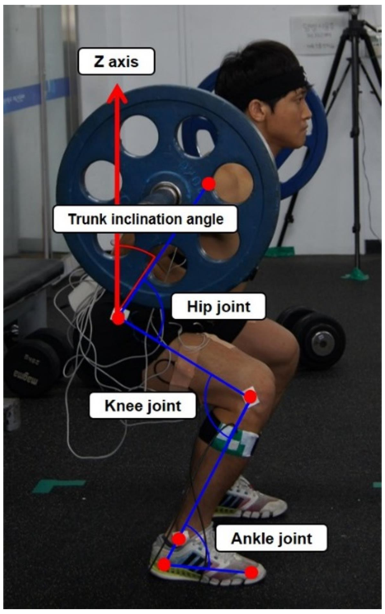

Figure 3. Joint angle

RESULTS

1. Muscle activity

1) Average integrated EMG (IEMG) in the flexion phase

No significant difference in the mean EMG value was found according to the exercise intensity during the flexion phase for all muscles (Table 2).

Table 2. Average IEMG in the flexion phase (%DMC)

	40%1RM	60%1RM	80%1RM
R. RF	19.3±6.3	24.4±8.4	28.3±10.5
L. RF	22.1±5.9	27.2±6.8	31.0±8.7
R. BF	7.1±2.1	10.1±3.1	13.1±4.3
L. BF	11.5±3.4	15.1±5.0	18.4±8.0

2) Average IEMG in the extension phase

The mean EMG value of the RF significantly increased at 80%1RM compared with 40%1RM during the extension phase (Table 3).

2. Kinematic variables

1) Temporal parameter

No significant difference in the mean duration of the flexion phase was found according to the intensity setting. However, the duration of the flexion phase significantly increased at 80%1RM compared with 40%1RM and 60%1RM (Table 4).

Table 3. Average IEMG in the extension phase (%DMC)

	40%1RM	60%1RM	80%1RM
R. RF	19.9±8.0*	27.0±9.5	34.2±10.5*
L. RF	19.1±4.5*	26.7±7.6	31.1±6.6*
R. BF	12.5±4.3	21.9±4.5	27.9±6.0
L. BF	18.6±3.5	28.5±7.1	35.1±6.9

Note. *Significant difference between 40%1RM and 80%1RM.

Table 4. Temporal parameter (s)

	40%1RM	60%1RM	80%1RM
Flexion phase	1.467±0.344	1.379±0.387	1.467±0.331
Extension phase	1.176±0.284*	1.112±0.186#	1.442±0.223*#

Note. *Significant difference between 40%1RM and 80%1RM.
#Significant difference between 60%1RM and 80%1RM.

2) Joint angle

The joint angle of the knee significantly increased at 80%1RM compared with 40%1RM at the point of flexion. However, no significant difference was found for all other joint angles according to the intensity setting (Tables 5~8).

Table 5. Joint angle of the hip (deg)

	40%1RM	60%1RM	80%1RM
Extension 1	160.9±4.2	158.9±3.2	158.9±4.4
Flexion	73.6±7.9	75.2±6.9	77.2±8.2
Extension 2	159.0±4.7	157.6±5.2	158.0±4.5

Table 6. Joint angle of the knee (deg)

	40%1RM	60%1RM	80%1RM
Extension 1	170.3±4.7	168.7±4.0	167.9±3.7
Flexion	75.3±8.4*	77.1±10.0	80.8±8.0*
Extension 2	168.3±5.7	167.3±5.0	168.0±3.8

Note. *Significant difference between 40%1RM and 80%1RM.

Table 7. Joint angle of the ankle (deg)

	40%1RM	60%1RM	80%1RM
Extension 1	85.5±4.5	84.6±4.2	84.2±3.3
Flexion	58.4±4.6	58.3±5.5	59.4±4.4
Extension 2	85.5±3.9	84.7±4.0	85.5±4.2

Table 8. Trunk inclination angle (deg)

	40%1RM	60%1RM	80%1RM
Extension 1	8.6±3.0	9.4±2.8	8.7±3.4
Flexion	32.6±4.5	32.4±3.7	32.7±6.1
Extension 2	9.3±2.9	9.6±4.1	9.5±3.8

3) Range of motion

The range of motion of the knee joint significantly increased at 80%1RM compared with 40%1RM and 60%1RM during the flexion and extension phases. However, no significant differences in the range of motion were found for all other joints (Tables 9~12).

Table 9. Range of motion of the hip (deg)

	40%1RM	60%1RM	80%1RM
Flexion phase	87.3±10.8	83.7±8.1	81.7±7.8
Extension phase	85.4±10.7	82.4±9.0	80.8±8.4

Table 10. Range of motion of the knee (deg)

	40%1RM	60%1RM	80%1RM
Flexion phase	95.0±11.2*	91.6±11.3#	87.1±7.2*#
Extension phase	93.1±11.4*	90.2±11.7#	87.1±8.1*#

Note. *Significant difference between 40%1RM and 80%1RM.
#Significant difference between 60%1RM and 80%1RM.

Table 11. Range of motion of the ankle (deg)

	40%1RM	60%1RM	80%1RM
Flexion phase	27.1±4.3	26.3±5.3	24.8±3.9
Extension phase	27.0±4.6	26.3±5.1	26.1±4.3

Table 12. Range of motion of the trunk (deg)

	40%1RM	60%1RM	80%1RM
Flexion phase	23.9±3.7	23.0±2.2	23.9±5.3
Extension phase	23.3±3.2	22.8±3.1	23.2±5.7

4) Angular velocity

The angular velocity of the knee joint significantly decreased at 80%1RM compared with 40%1RM and 60%1RM during the flexion phase. The angular velocity significantly decreased for all joints at 80%1RM compared with 40%1RM and 60%1RM during the extension phase (Tables 13~16).

Table 13. Angular velocity of the hip (deg/s)

	40%1RM	60%1RM	80%1RM
Flexion phase	62.6±16.4	64.4±15.9	58.0±13.2
Extension phase	76.0±18.5*	75.5±11.7#	57.3±11.4*#

Note. *Significant difference between 40%1RM and 80%1RM.
#Significant difference between 60%1RM and 80%1RM.

Table 14. Angular velocity of the knee (deg/s)

	40%1RM	60%1RM	80%1RM
Flexion phase	68.4±18.6*	70.4±18.3#	61.8±13.9*#
Extension phase	83.1±21.6*	82.7±14.8#	62.2±13.8*#

Note. *Significant difference between 40%1RM and 80%1RM.
#Significant difference between 60%1RM and 80%1RM.

Table 15. Angular velocity of the ankle (deg/s)

	40%1RM	60%1RM	80%1RM
Flexion phase	19.4±5.7	20.1±6.0	17.5±4.3
Extension phase	24.2±7.3*	24.2±5.9#	18.6±4.4*#

Note. *Significant difference between 40%1RM and 80%1RM.
#Significant difference between 60%1RM and 80%1RM.

Table 16. Angular velocity of the trunk (deg/s)

	40%1RM	60%1RM	80%1RM
Flexion phase	16.9±3.6	17.6±4.2	17.0±5.2
Extension phase	20.6±4.6*	20.7±2.7#	16.4±4.0*#

Note. *Significant difference between 40%1RM and 80%1RM.
#Significant difference between 60%1RM and 80%1RM.

DISCUSSION

Consistent with the findings of Steven & Donald (1999), this study demonstrated that the activity of the lower-extremity muscles increases as exercise intensity increases during squat exercise. Notably, the femoral muscle activity was more significantly increased at 80%1RM than at 40%1RM at the point of extension. This suggests that the activity of femoral muscles increases to support the increased load as exercise intensity is increased, and to control the instability of the body (Lee et al., 2011). Furthermore, when performing the extension movement during squat exercise, the exerciser must use a quick force of the femoral muscles and maintain joint stability, and it appears that the increased femoral muscle activity may be the result of this mechanism (Chae et al., 2007).

While similar durations of the flexion phase were found regardless of exercise intensity, the duration of the extension phase was more significantly increased at 80%1RM than at 40%1RM and 60%1RM. In their kinematic analysis of squat exercise, Bak, Shin, and Shin (2015) reported that the extension movement can be performed relatively faster than the flexion movement during the typical squat exercise. This may be because while the flexion movement is performed relatively slowly to maintain a stable posture and maximize muscle stimulation, the extension movement is performed relatively faster through concentric contraction of the femoral muscles, which are agonistic muscles. In this study, the durations for each phase at 40%1RM and 60%1RM were similar to those reported by Bak et al. (2015). However, the duration of the extension movement was increased at 80%1RM in this study. These results suggest that the duration of the extension movement becomes longer to overcome an increase in the mass of the external load that is applied downward owing to the force of gravity as exercise intensity is increased during squat exercise.

As exercise intensity increased, the joint angle of the knee increased at the point of flexion, and the range of motion of the knee joint decreased during the flexion and extension phases. It is possible that the range of motion of the body was intentionally restricted to compensate for the excessive muscle activity and postural instability due to increased exercise intensity (Anderson & Behm, 2005). Increasing the load during squat exercise can make it more difficult to properly perform a movement and maintain a stable posture, thereby negatively affecting the exercise outcome and possibly increasing the risk of injury (Rao et al., 2009). The tilt angle and the range of motion of the upper body at different time points during squat exercise were maintained uniform regardless of the exercise intensity. Consistent with the report of Thomas & Roger (2006), which suggested that the exerciser must be careful not to tilt the upper body forward during a squat to avoid applying excessive load on the spine, the upper body movement was adequately controlled to perform a stable movement in this study.

During the squat exercise, the angular velocity was significantly reduced at 80%1RM relative to 40%1RM and 60%1RM at the knee joint during the flexion phase, and at all joints during the extension phase. In resistance exercises in which external loads are used to set exercise intensity, such as squat exercise, the angular velocity of the joint decreases as exercise intensity increases. This phenomenon may be attributed to the muscle force-velocity relationship in which movement velocity decreases as muscle force increases (Kenney et al., 2015). Therefore, the result of this study, showing that the angular velocity of the joint decreased as the external load was increased, corresponds to this relationship.

CONCLUSION

During resistance exercises, movement speed and muscle force are related such that movement speed decreases as muscle force increases. In this study, the femoral muscle activity was observed to increase during the extension phase as the exercise intensity increased, whereas the angular velocity decreased during squat exercise. Because agonistic muscles undergo eccentric contraction and concentric contraction during the flexion and extension phases of squat exercise, respectively, it appears that the joint angular velocity decreased during the extension phase to overcome the increased load when the exercise intensity was increased. Furthermore, the range of motion of the knee joint was found to be restricted when a heavy load was applied to the body due to increased exercise intensity. These results suggest that it is important to concentrate on the contraction of agonistic muscles while maintaining uniform exercise tempo and knee joint movements in order to perform proper squat movements.

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