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KINEMATIC ANALYSIS OF FRONT SQUAT IN RESPONSE TO LOADS

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The purpose of this study was to examine the kinematics of lower extremity and spine in response to different mass loads in front squat exercise. Three experienced male varsity athletes were recruited to participate in this study, and each participant performed five trials of front squat exercise at three different loads (65%, 75%, and 85% of 1 repetition maximum). A standard two-dimensional kinematic analysis was conducted and the result showed that the participants had no significant difference on different loads in both lower extremity and spine. However, the knee joint demonstrated a strong sensitivity in response to load mass, so a strength training program may be prescribed focusing on the knee joint stability. Future research studies are warranted to examine the kinematic differences between a knee-braced front squat and a plain front squat.

KEYWORDS: core, lumbar, spine, weight lifting

INTRODUCTION: Squatting is an important core exercise for therapists, trainers, sports medicine physicians, researchers, coaches, and athletes in terms of injury prevention and sports performance improvement (Escamilla, 2001).The squat also becomes increasingly popular in clinical settings as a mean to strengthen lower-body muscles and connective tissue after joint-related injuries (Brad, 2010). As a result, coaches and trainers believe that squatting exercise may help athletes reduce injuries and increase performance improvement. However, performing a squat exercise with improper technique may potentially cause joint-related injuries in lower extremities including spine, knee, and ankle due to the amount of forces from the mass of the barbell that is placed on the joints. When performed properly, squat–related injuries are uncommon (Watkins,1999). However, documented injuries from squatting include muscle and ligamentous sprains, ruptured interverebral discs, spondylolysis, and spondylolisthesis (Vakos, Nitz, Threlkeld, Shapiro, & Horn, 1994). The spine is a very intricate column composed of vertebrae, intervertebral discs, nerves, and the spinal cord. The spine extends from the skull to the pelvis and is made up of 33 individual vertebrae that are separated by the intervertebral discs which act as shock absorbers. The spines vertebrae are divided into five sections from the neck to the tail bone: cervical, thoracic, lumbar, sacrum, and coccyx. Of the five sections dividing the spine, the lumbar region is by far the most prone to injury. It has been estimated that up to 80% of adults will eventually develop some form of low back pain. Additionally, it has been estimated that 10-15% of all sporting injuries involve the spine (Durall & Manske, 2005). Because of this, the squat exercise which puts heavy stress on the spinal joints has to be performed with extensive care and causion. There are different types of squat exercise including back squat, front squat, and power squat. Front squat is a unique exercise because it has more anterior inclination of the upper body position due to stress points where the forces from the weights that are put on. Some coaches and trainers believe that front squat exercise may be more beneficial to the athletes because the anterior inclination of the upper body postion better represents the acceleration phase of a sprint start. However, the proper front squat technique and the changes in spine and lower extremity joints in response to load mass remained to be addressed. Therefore, the purpose of this study was to examine the kinematic analysis of the lower extremity and spine in front squat exercise in response to different mass loads.

METHODS: Three experienced varsity male lifters between the ages of 18 and 25 were recruited to participate in this study. Participants had all participated in weightlifting for at least 6 years prior to the study and were experienced with front squat exercise. Institutional ethics review board approved the study, and written informed consent was obtained from each participant prior to the study. All participants arrived to a fitness center for their first testing session. During the first testing session, participants performed a general warm up. They were then asked to perform two sets of front squat to familiarize themselves with the exercise and movement patterns. Then, each participant was asked to perform front squat six times (6 repetition maximum) while maintaining appropriate form. The purpose of the first testing was to determine each particpant's estimated one repetition maximum in front squat exercise. During the second session, which was to be no sooner than three days following the first testing session to ensure sufficient amount of recovery, all participants arrived to the laboratory. Thirteen joint reflective markers were placed on the right side of the body including participant's forehead, chin, shoulder (greater tubercle), elbow (lateral epicondyle of humerus), wrist (styloid process of the radius), hip (greater trochanter), knee (lateral epicondyle of the femur), ankle (lateral malleolus), toe (fifth metatarsal), and three locations of the spine (approximately T6, L3, and S1) plus at the end of bar. The participants were asked to wear spandex shorts and no shirt. Following a general warm up, the participants were asked to perform five repetions at 65%, 75%, and 85% of 1 RM. The order of the front squat load was randomly assigned to reduce order effect. Recovery time between each set was approximately 3 minutes. A spotter was present during the testing to ensure safety. Data collection was conducted in one session and was approximately 45 minutes in duration for each participant. A JVC video camera (Model: GR-D371V) was used to capture the kinematic movement at 60 frames per second in the sagittal view. Also, a 650W artificial lighting was used to assist in identifying the joint reflective marker. All video trials were then transferred onto a computer in the Biomechanics Lab. The first and the last trial of each set were not used for data analysis. A standard two-dimensional kinematic analysis was conducted with Ariel Performance Analysis system (APAS) software, and the digital filter funtion was applied at 8 Hz. A one-way repeated measure ANOVA was conducted at $\alpha = 0.05$ and followed by a t-test with Bonferroni adjustment if a significant difference was found. All statistical analysis was conducted with SPSS (v. 18) software.

RESULTS AND DISCUSSION: The results showed no statistical significant differences in the joint angle displacement at the hip, knee, and ankle. Also, no statistical significant difference was found between different loads in the lumbar spine, Table 1.

Table 1
Angular Displacement of Lower Extremities in Front Squat

Comparisons	Mean (SD)°			*p*
Spine				
65% vs. 75%	173.8(1.3)	vs.	174.2(1.5)	0.23
75% vs. 85%	174.2(1.5)	vs.	173.5(3.2)	0.51
65% vs. 85%	173.8(1.3)	vs.	173.5(3.2)	0.76
Hip				
65% vs. 75%	61.4(11.3)	vs.	62.1(15.0)	0.78
75% vs. 85%	62.1(15.0)	vs.	60.4(12.5)	0.62
65% vs. 85%	61.4(11.3)	vs.	60.4(12.5)	0.79
Knee				
65% vs. 75%	59.6(4.3)	vs.	56.2(5.1)	0.19
75% vs. 85%	56.2(5.1)	vs.	59.7(3.9)	0.32
65% vs. 85%	59.6(4.3)	vs.	59.7(3.9)	0.94
Ankle				
65% vs. 75%	91.9(2.6)	vs.	89.4(3.7)	0.11
75% vs. 85%	89.4(3.7)	vs.	90.2(4.2)	0.23
65% vs. 85%	91.9(2.6)	vs.	90.2(4.2)	0.36

* Statistical significant at $p < 0.017$

Further, from the result of the study it was revealed that there was no statistical significant difference in the joint angular velocity at the spine, hip, knee, and ankle, Table 2. However, a trend was observed that as the load mass increased, the knee joint angular velocity decreased. Moreover, no statistical significance differences were observed in the joint angular acceleration in all the joints in the lower extremity and the spine. Interestingly, a trend was also observed in both hip and knee joints in the angular acceleration. The results showed that as the load mass increased, the angular acceleration of the hip increased as well (65% =1005.5 ± 563.2 °/s^2, 75% =1936.6 ± 43.7 °/s^2, and 85% = 2394.6 ± 1120.5 °/s^2). However, as the load mass increased, the angular acceleration of the knee decreased (65% = 964.9 ± 238.0 °/s^2, 75% = 957.9 ± 202.4 °/s^2, and 85% = 856.6 ± 330.1 °/s^2).

Table 2
Angular Velocity of Lower Extremities in Front Squat

Comparisons	Mean(SD)°/s			*p*
Spine				
65% vs. 75%	26.6(27.0)	vs.	17.4(21.8)	0.21
75% vs. 85%	17.4(21.8)	vs.	21.4(25.1)	0.17
65% vs. 85%	26.6(27.0)	vs.	21.4(25.1)	0.37
Hip				
65% vs. 75%	10.0(0.9)	vs.	18.2(3.9)	0.09
75% vs. 85%	18.2(3.9)	vs.	17.0(7.3)	0.76
65% vs. 85%	10.0(0.9)	vs.	17.0(7.3)	0.28
Knee				
65% vs. 75%	7.3(3.6)	vs.	5.9(2.4)	0.67
75% vs. 85%	5.9(2.4)	vs.	4.7(1.7)	0.59
65% vs. 85%	7.3(3.6)	vs.	4.7(1.7)	0.14
Ankle				
65% vs. 75%	2.4(1.0)	vs.	3.6(1.9)	0.35
75% vs. 85%	3.6(1.9)	vs.	2.2(1.6)	0.34
65% vs. 85%	2.4(1.0)	vs.	2.2(1.6)	0.90

* Statistical significant at $p < 0.017$

In this study the authors hypothesized that the spine joint angle would increase as the load mass was increased; however, the results showed that the spine joint angle remained quite similar in all three different mass loads in the front squat exercise. This finding is different from a previous research study that suggests a decrease in the lumbar angle can be observed with an increase in load mass in the back squat exercise (List, Gülay, & Lorenzetti, 2010). Additionally from the major difference in the two squatting techniques (front squat vs back squat) between the two studies, another factor that may be attributed to the difference is the sample population. In this study experienced varsity athletes were used instead of experienced movement science students. Further, another major factor may be the % load mass. In this study the % load mass of subjects' 1 RM was used instead of % load mass of subject's body weight. This study showed a trend of decreasing in both angular velocity and acceleration at the knee joint as the % load mass was increased from 65% to 85% of 1 RM. This indicated that athletes flexed their knee joint at a slower rate to adapt to higher % load mass. This technique lifting adjustment may have allowed the athletes to maintain a proper lumbar spine curvature. A strength training program may be prescribed to focus on the knee joint stability and muscle strength improvement for the quadriceps and hamstrings. Future research studies are warranted to examine the kinematic differences between a knee-braced front squat and a plain front squat. In this study experienced varsity athletes were used instead of experienced movement science students. Further, another major factor may be the % load mass. In this study the % load mass of subjects' 1 RM was used instead of % load mass of subject's body weight. This study showed a trend of decreasing in both angular velocity and acceleration at the knee joint as the % load mass was increased from 65% to 85% of 1 RM. This indicated that athletes flexed their knee joint at a slower rate to adapt to higher % load mass. This technique lifting adjustment may have allowed the athletes to maintain a proper lumbar spine curvature. A strength training program may be prescribed to focus on the knee joint stability and muscle strength improvement for the quadriceps and hamstrings. Future research studies are warranted to examine the kinematic differences between a knee-braced front squat and a plain front squat.

CONCLUSION: This research study used experienced weight lifter to examine the mechanics of the front squat exercises in response to different loads of 1RM, and the results did not show any statistical significant difference in the spine, hip, knee, and ankle. However, a downward trend was observed in the angular velocity and acceleration of the knee joint as the % load mass was increased. This study provides a preliminary understanding about front squat movement in response to different loads and suggests the importance of prescribing strengthening exercise targeting the knee joint. Future research studies are warranted to examine the kinematic differences between a knee-braced front squat and a plain front squat exercises.

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