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A BIOMECHANICAL ANALYSIS OF FRONT VERSUS BACK SQUAT: INJURY IMPLICATIONS

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The aim of this study was to examine the differences in trunk and lower limb kinematics between the front and back squat. 2D kinematic data was collected as participants (n = 12) completed three repetitions of both front and back squat exercises at 50 % of their back squat one repetition maximum. Stance width was standardised at 107(±10) % of biacromial breadth. The Wilcoxon signed ranks test was used to examine significant differences in dependent variables between both techniques. Results showed that the back squat exhibited a significantly greater trunk lean than the front squat throughout ($p < 0.05$) with no differences occurring in knee joint kinematics. The results of this study in conjunction with other squat related literature (Russell *et al.,* 1989) suggest that the back squat gives rise to an increased risk of lower back injury.

KEYWORDS: Strength & Conditioning, Resistance Training, 2D Kinematics.

INTRODUCTION: The back and front squat are popular exercises prescribed to strengthen the lower-limb musculature (Braidot *et al*., 2007). Research to date has focused largely on parameters of back squat performance (Escamilla *et al*., 2001), with little attention given to its front variation. Russell and Phillips (1989) noted that the anterior bar position utilised during the front squat increases quadriceps muscle activation which may enhance strength development relative to the back squat. While the capacity of both techniques to enhance quadriceps development may be of importance to the exercise professional, perhaps of greater importance are the potential injury risks associated with their action. Escamilla *et al*. (2001) reported that progressive knee flexion, occurring as the performer descends past the parallel mid-point position, increases compressive forces occurring at the patellofemoral and tibiofemoral joints as well as increasing tibiofemoral shear forces. Under regular high loading conditions (e.g.: one-repetition maximum; 1RM), such an increase in compressive and shear forces may exceed the strain capabilities of the joints connective tissues, predisposing the performer to injury (Comfort and Kasim, 2007). Further to this, while performing the back squat action, the performer is required to adopt a flexed upper body position at the mid-point of the exercise in order to maintain balance (Figure 1a). Conversely, the front squat allows for a more upright posture throughout (Figure 1b). Comfort and Kasim (2007) noted that increasing trunk lean (i.e.: trunk flexion away from a neutral upright position) may result in greater shear forces occurring at the lumbar spine, posing a considerable injury risk for this technique.

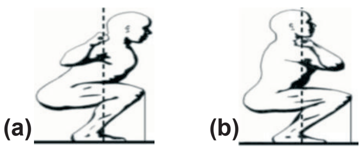

Figure 1: Fundamental body position occurring at the mid-phase of (a) back squat and (b) front squat.

Russell and Phillips (1989) examined the 2D kinematics of both squatting actions and noted a greater trunk lean throughout the back squat performance, relative to that of the front squat. In analyzing these differences the authors allowed participants to adopt a self-selected stance width. Escamilla *et al*. (2001) noted that while flexion and extension movements of the trunk occur primarily in the sagittal plane, knee joint actions may deviate if stance width and foot positions are not standardized. In 2D analysis, this may introduce unwanted parallax to the data (Escamilla *et al*., 2001). With this in mind the aims of this study were to assess the kinematic differences occurring between both front squat and back squat techniques using 2D video analysis employing standardised stance parameters. It was hypothesised that performers would exhibit significantly greater trunk lean during back squat performances relative to the front squat, with little variation occurring in knee joint kinematics.

METHODS: Participant Characteristics: Twelve volunteers (age 20.3 (±1.4) years, height 1.79 (±0.4) m, mass 85 (±11.3) kg) were recruited from a semi-professional rugby academy. At the time of testing, each participant was injury free and had been performing both squatting techniques weekly for at least 12 months prior to the study. All testing procedures were approved by the department ethics committee of the University of Limerick and all participants provided written informed consent.
Data Collection: Retro-reflective markers were placed on five anatomical locations (5^{th} metatarsal, lateral malleolus, lateral epicondyle of the femur, greater trochanter, mid-axilla) based on the recommendations of Davis *et al*. (1991). Following a standardized warm-up, participants were required to perform 3 repetitions of both back and front squat techniques at 50% of their 1RM (determined from coach's records). Participants were provided with 5 minutes recovery between performances of both techniques. In order to limit the effects of parallax on 2D kinematic data, stance width was standardised at 107 (±10) % of biacromial breadth, measured using an anthropometer (Escamilla *et al*., 2001). Kinematic data were recorded using a JVC Everio HDD camcorder recording at 25Hz (shutter speed 1/120 s).
Data Analysis: Video footage was analysed using Siliconcoach 7 (Dunedin, NZ). Movement time was normalised into nine time-points to control for inter-individual differences in movement velocity. The path of each joint marker was manually digitised at a rate of 25 Hz throughout both eccentric and concentric phases. Changes in the relative angle of the knee and the absolute angle of the trunk (the angle between hip and mid-axilla with the vertical) throughout the downward and upward phases were examined. Wilcoxon signed ranks test was used to examine statistical differences in trunk lean angle and knee joint angle between both squatting techniques. Effect sizes (r) were calculated ($r = z/\sqrt{N}$) and analysed for small, medium and large effects based on Cohen's benchmark (Field, 2009).

RESULTS: Figure 2 shows the mean (±SD) changes in relative knee joint angle throughout the eccentric and concentric phases of both squatting actions. Results show a progressive decrease in knee joint angle throughout the eccentric phase for both techniques. Relative knee angle reached maximum flexion at 91.1˚ for the back squat and 91.7˚ during the front squat at the bottom of the eccentric phase. Subsequently, during the concentric phase knee joint angle increased progressively to maximal extension. The data shows a similar change in knee joint angle throughout each movement phase between both squatting techniques. This is supported by statistical results showing no significant differences ($p<0.05$) at any phase between both squatting actions.

Figure 2: Mean (± SD) changes in relative knee joint angle throughout front and back squat performances.

Figure 3 shows the mean (±SD) changes in absolute trunk lean throughout the eccentric and concentric phases of both the back and front squat actions. As participants moved through the eccentric phase trunk lean increased progressively, peaking at mid-phase for both techniques. Following this, trunk lean decreased progressively as participants extended towards the starting position. The data show that the posterior bar position adopted during the back squat caused a greater trunk lean throughout each phase. For instance, during phase 1, participants exhibited a mean trunk lean of 6.2º (±3.4º) when performing the back squat while during the front squat they adopted a more upright trunk position (mean = 4.2º ± 1.7º). Statistical analysis revealed that this 32% difference was not significant ($z = -1.412$; $p>0.05$). As participants moved through subsequent phases, the magnitude of this difference increased progressively, reaching a maximum (37.8%) at mid-phase. Wilcoxon signed ranks test results showed that this difference became significant from phases 2-9 (phases 2, 4-6, $z = -3.059$; phases 3 and 7, $z = -3.061$; phase 8, $z = -2.589$; phase 9, $z = -2.353$; $p<0.05$). Calculation of effect sizes illustrates that these differences exhibited large effects ($r = -0.679$ to -0.883).

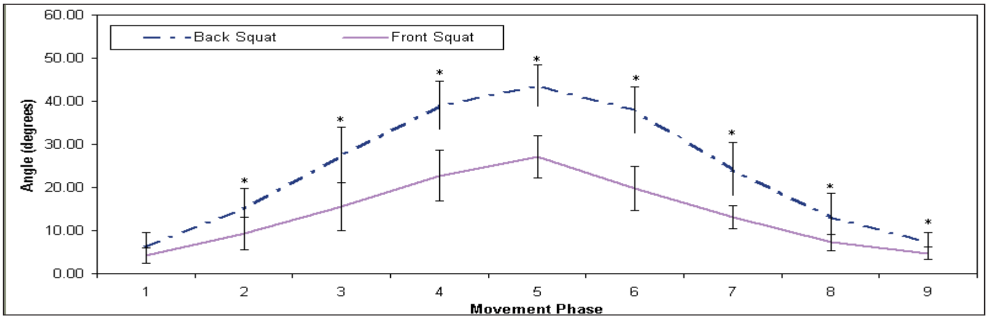

Figure 3: Mean (± SD) changes in relative absolute trunk lean angle throughout front and back squat performances. (* $p < 0.05$).

DISCUSSION: This study attempted to assess the kinematic differences occurring between both front and back squat techniques using 2D video analysis while standardising stance parameters. In keeping with previous research, results showed similar knee joint movement patterns with substantial differences occurring in trunk lean kinematics between both squatting actions (Russell and Phillips, 1989; Braidot *et al*., 2007). Previous researchers however did not control stance parameters thus references made to 2D knee joint kinematics should be approached with caution. In the present study, stance parameters were standardised in keeping with the recommendations of Escamilla *et al*. (2001). Data showed that participants' knee joint angle decreased progressively throughout the eccentric phase of the movement achieving a maximum flexion angle of 91º for both techniques. This suggests that when squatting to a parallel femur position, both techniques may exhibit similar muscle activation levels, a hypothesis supported by Gullet *et al*. (2009). Gullet and colleagues (2009) also noted however that while muscle activation levels are similar, the front squat exhibited significantly less tibiofemoral compressive forces and knee extensor moments. This is supported by Figure 4(a) which shows the fundamental bar position adopted for both the back and front squat techniques and resulting knee joint resistance moment arms. Fw represents the weight of the bar (i.e.: bar + load) acting vertically downward. It may be that the anterior bar position adopted during the front squat may reduce the knee joint resistance moment arm length (Mk_{fs}) relative to that experienced during the back squat (Mk_{bs}). This would reduce the knee extensor torque experienced during the front squat relative to that experienced with a posterior bar position.

Of further importance to the present study are the differences in trunk lean angle between both techniques. Data showed that throughout the squatting action, participants exhibited a greater trunk lean for the back squat relative to the front squat. These differences changed from an insignificant 32 % difference at phase 1, to a significant maximum of 37.8 % at phase 5 ($p<0.05$). Effect size calculations illustrated this difference to be a large effect (Field, 2009). Figure 4(b) shows the fundamental bar position adopted for both the back and front squat techniques and resulting lumbar resistance moment arms. In both squatting actions, as the performer lowers throughout the eccentric phase, they are required to lean forward in order to maintain balance. Subsequently the mass of the bar moves further away from the axis of rotation (lumbar spine), increasing the moment arm of Fw (i.e.: Mt_{bs} and Mt_{fs}) and its resulting torque. As a result the shear forces occurring within the lumbar spine would also increase. With this in mind, it may be that the greater trunk lean occurring throughout performance of the back squat would exhibit greater shear lumbar loading, a theory supported by Russell and Phillips (1989). As previously stated such an increase in shear force, under regular high loading conditions (e.g.: 1 RM), may predispose an athlete to injury if these forces continually exceed the strain capabilities of the joints connective tissues (Comfort and Kasim, 2007).

Figure 4: Fundamental body position and resulting (a) knee and (b) trunk resistance moment arms occurring at the mid-phase of back and front squat techniques.

CONCLUSIONS: The results of this study in conjunction with the aforementioned literature show that the front squat would present the least risk of injury to the lower back and knee joint, while offering the same ability to strengthen the knee extensors as the back squat technique. The front squat also allows the performer to maintain a more upright posture throughout, a characteristic congruent with most sporting techniques (e.g.: sprinting). This would imply a greater level of specificity for this technique. It is recommended that coaches and exercise professionals consider these points when prescribing a specific squatting technique.

Future research should endeavor to estimate the kinetic effects of these differences by employing inverse dynamics to determine the effects of changes in the resistance moment arms. Also, while squat depth was standardised in the present study, future research may well examine the kinetic implications of both techniques at various squatting depths.

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