PRELIMINARY STUDY: INTERPRETATION OF BARBELL BACK SQUAT KINEMATICS USING PRINCIPAL COMPONENT ANALYSIS

Kimitake Sato[1], Dave Fortenbaugh[2], and J. Kyle Hitt[1]

[1]University of Northern Colorado, Greeley, CO USA
[2]American Sports Medicine Institute, Birmingham, AL USA

The purpose of this study was to reduce the number of kinematic variables of the barbell back squat for easier interpretation by coaches and athletes. Young active adults (*N*=25) performed the back squat with an intensity of 60%. A total of 10 lower body and trunk measurements were considered for principal components analysis (PCA). Based on the PCA, two components were revealed. The primary component related range of motions (ROMs) in the ankle and knee joints with greater peak flexion angles of ankle, knee, and shank and thigh segments. A secondary component related hip ROMs and hip posterior displacement with greater hip and trunk segment peak flexion angles. Based on this analysis, coaches teaching the barbell back squat should consider two sources of movement variability, one above and one below the hip.

KEYWORDS: squat, kinematics, principal component analysis.

INTRODUCTION: The barbell back squat is a popular exercise among athletes and individuals who participate in resistance training. The National Strength & Conditioning Association (NSCA) initially published a position statement to guide coaches on how to instruct lifters to perform the squat correctly and safely based on a review of the available biomechanical research (Chandler & Stone, 1991). These guidelines have become a popular instruction manual among strength and conditioning coaches and personal trainers for two decades. More recent biomechanical studies have further measured joint kinetics and kinematics of the squat, from both performance and clinical perspectives (Flanagan & Salem, 2007; Fry, Smith, & Schilling, 2003; Salem, Salinas, & Harding, 2003). These studies have reported joint range of motions (ROMs) (Kongsgaard, Aagaard, Roikjaer, Olsen, Jensen, Langberg et al., 2006), peak flexion angles of the lower extremity joints and segments (Flanagan & Salem, 2007; Fry et al., 2003; Salem et al., 2003), and displacements of hip and barbell (Donnelly, Berg, & Fiske, 2006) to evaluate the lifting technique. The NSCA position paper (1991) also cites that injuries to the low back and knee during squatting are common among athletes who are undertrained or have poor technique, further emphasizing the importance of the biomechanical research on proper squat mechanics.

While the variables measured in biomechanical studies show important aspects of the squat kinematics, the sheer number of variables reported may be overwhelming for coaches when qualitatively analyzing a lifter's squat technique. There is a need to reduce the numbers of the kinematic variables to focus on fewer components to evaluate the squat performance.

Therefore, the purpose of the current study was to reduce the number of kinematic variables of the barbell back squat using a principal components analysis (PCA) to summarize the inter-correlated variables into components and create fewer variables to explain and analyze the kinematics of the back squat. A similar design has also been used in gait studies, and the PCA is a commonly used statistical procedure to reduce the number of variables for easier interpretations and analyses (Chester & Wrigley, 2008). Even though the PCA does not provide statistical significance, its information may benefit coaches and athletes to narrow the view points when assessing the squat technique.

METHODS: Twenty-five active college-aged students (20 male, 5 female) volunteered for this study (21±4 yrs.; 179±8 cm; 83±13 kg). All participants were relatively experienced in resistance training including the barbell back squat and free of injuries at the time of data collection. Those who were unfamiliar with the task were eliminated during the recruitment procedure to minimize measurement variance. A university Institutional Review Board approved all procedures and all participants provided their consent before testing.

All participants reported to the laboratory for data collection, and procedures of the testing protocol were provided. Each participant had an adequate amount of stretching and warm-up to replicate a regular training session. In order to normalize the footwear condition among participants, each wore weightlifting shoes (WerkSan, USA) to perform the barbell back squat. A 60-Hz Panasonic digital camera (Osaka, Japan) was placed approximately 1.3 m high and 5 m away on the left side to capture two-dimensional back squat kinematics in the sagittal plane. Reflective markers were placed on left side of the participant's 5th metatarsal joint (toe), lateral malleolus (ankle), lateral femoral epicondyle (knee), and greater trochanter (hip). An additional marker was placed on the end of the barbell. These five markers were used to create trunk, thigh, shank, and foot segments to calculate joint and segmental angles. A segment from the hip to the end of the barbell was used to approximate the trunk segment since the end of the barbell is in the fixed position of the shoulder joint (Fry et al., 2003; McLaughlin, Dillman, & Lardner, 1977).

As all participants were familiar with the barbell back squat, just a brief instruction was given to ensure the left foot was perpendicular to the camera position and the feet were pointed forward for proper tracking of the squat motion in the sagittal plane. If a participant felt uncomfortable with his or her feet pointing forward, practice sets were provided. Also, for those who were not familiar with the weightlifting shoes, practice sets were offered to gain familiarity with the shoes. In order to achieve a comparable effort level from all participants, all trials were performed at 60% of 1RM. For each squat repetition, subjects began standing erect with the barbell on the upper back and descended until the thigh segment was roughly parallel to the floor, and then ascended back to the starting position. Each participant performed a set of five repetitions. The squat video was captured and the data were directly imported into Vicon Motus version 9.2 software (Centennial, CO) for motion analysis.

Two of the five repetitions were averaged and used for calculation purposes. The two repetitions chosen were the third and fourth repetitions in all participants. The kinematic variables measured are shown in Figure 1: (a) trunk segment angle, (b) hip joint angle, (c) thigh segmental angle, (d) knee joint angle, (e) shank segmental angle, and (f) ankle joint angle. ROMs, peak flexion angles of hip, knee, and ankle joints, and angles at the maximum descent position of the trunk, thigh, and shank segments were considered. In addition, a posterior hip displacement was also included. The 10 variables of the squat kinematics were subjected to PCA using Statistical Package for Social Sciences (SPSS) version 17 (Chicago, IL). The PCA was chosen for specifically to reduce the number of the dependent variables by grouping those that are highly correlated with one another.

RESULTS: Prior to performing the PCA, the appropriateness of data was assessed. Inspection of the correlation matrix revealed the presence of many coefficients of 0.5 and above. The Kaiser-Meyer-Oklin value was 0.65 (exceeding the recommended value of 0.60), and Bartlett's test of Sphericity reached statistical significance (p<0.001), indicating the factorability of the correlation matrix. The PCA revealed the presence of 2 components with eigenvalues exceeding 2, explaining a total of 77.3% of the variance (52.7% and 24.7%, respectively). This was supported by the results of the parallel analysis, which showed only two components with eigenvalues exceeding the corresponding criteria values for a randomly generated data matrix of the same size. In order to better interpret the two components, oblimin rotation was performed. The rotated solution revealed the presence of a simple structure with both components showing a number of strong loadings and all variables loading substantially on only one component (see Table 1).

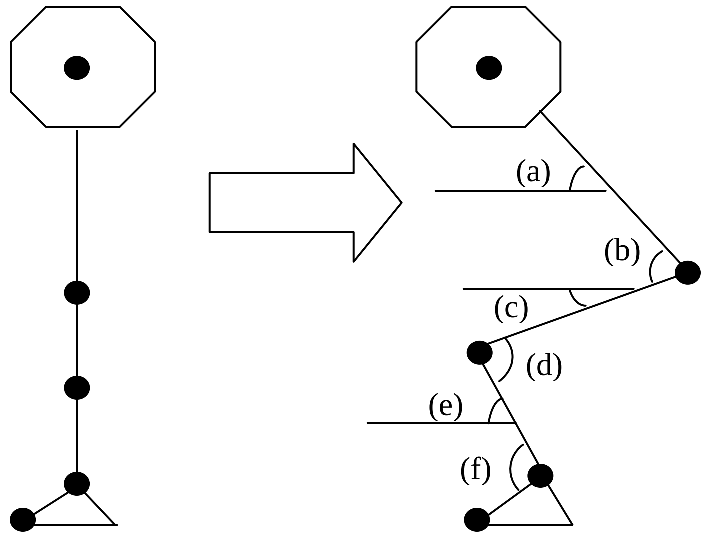

Figure 1. Diagram of kinematic variables measured during squat.

Table 1. Pattern Matrix

Variables	Component 1	Component 2
Knee peak flexion	0.929	
Ankle peak dorsiflexion	0.902	
Shank peak flexion	0.897	
Knee ROM	-0.884	
Ankle ROM	-0.877	
Thigh peak flexion	0.740	
Hip peak flexion		-0.780
Hip posterior displacement		0.742
Hip ROM		0.728
Trunk peak flexion		-0.699

DISCUSSION: The purpose of the current study was to reduce the large number of kinematic variables of the barbell back squat to summarize the inter-correlated variables into components and create new and fewer variables to explain the kinematics of the back squat. The results revealed two independent components. The first component seems to gather the variables from below the hip. It can be interpreted that greater ROMs in the ankle and knee joints created greater peak flexion angles of ankle and knee joints and thigh and shank segments. The second component involved kinematic variables at or above the hip. Based on the pattern matrix in Table 1, it can be interpreted that greater hip ROM leads to greater hip and trunk peak flexion angles and hip posterior displacement. This component seems accurate from a practical view that a greater amount of hip flexion leads to a shift of the pelvis in the posterior direction, and as a result, the lifter leans forward more to balance out the body position at the peak descent position of the back squat. This outcome is also consistent with Fry et al. (2003), who investigated kinematic differences on restricted and unrestricted knee position during the back squat. Their results showed that the restricted knee position (i.e. knees stay over the toes) caused greater hip and trunk flexion angles to lower the barbell to a desired height as compared to the unrestricted knee position.

Another interesting part from this analysis is that two components were separated clearly from above and below hip, indicating that peak hip and trunk flexion angles are independent of ankle and knee kinematics. Coaches and athletes can use this information to focus on two distinct areas when analyzing the squat performance. For example, if a lifter exhibits excessive trunk flexion, it is most likely not caused by the lower extremity kinematics, but rather movements at the hip with greater flexion and posterior displacement. Therefore, correcting excessive trunk flexion through changes in knee and ankle flexibility may not be the best solution. Another example is that a lack of hip flexibility is very common among athletes (Brophy, Chiaia, Maschi, Dodson, Oh, Lyman, et al., 2009), but it does not necessarily reflect ankle and knee ROM limitations during the back squat. To compare results of the present study with an outcome from Dollenney et al. (2006), the downward gaze of lifters relates to the movement of the trunk and hip, but may not relate to the lower extremity kinematics.

CONCLUSION: The PCA revealed two main components that affect squat technique: one involving movement at or above the hip and one involving movement below the hip. These two components are independent of one another. To evaluate squat performance, coaches and athletes can qualitatively analyze a lifter's technique by simply focusing on these two components.

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Acknowledgments

Authors would like to acknowledge WerkSan, USA, an official sponsor of USA Weightlifting for supplying weightlifting shoes as a part of this study.