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Review Article

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Variations of The Bilateral Barbell Squat: A Brief Review

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Abstract

The three most fundamental variations of the barbell squat with the bar placed on the shoulders are the high-bar back squat (HBBS), the low-bar back squat (LBBS), and the front squat (FS). There are significant kinematic, kinetic, and biomechanical distinctions between these variations that should be considered in the exercise selection. In comparison to the high-bar variations, the LBBS results in a greater hip joint torque and greater activation of the hip extensor muscles. In contrast, during the FS, the m. quadriceps is utilized more compared to the other two variations due to an increased torque in the knee joint. Regarding the relation between hip and knee joint torques, the HBBS is an intermediate and more balanced exercise variation than the LBBS and the FS. The HBBS is a fundamental exercise in athletic conditioning and a suitable starting point for novices, whereas the LBBS is preferred when the primary objective is to maximize weightlifting performance. The FS is crucial for athletes performing the clean and its derivates since it trains the required body position for a successful catch and might be the biomechanically advantageous variation if the goal is to target the knee extensor muscles. However, the differences in terms of knee extensor demands, muscle activation and kinematics between the HBBS and FS seem to be minimal, as the literature indicates similar results when comparing the FS to the HBBS. As far as analysis methods are concerned, even though 3D movement analysis is regarded as the gold standard for motion capture and analyzing kinematics, 2D models seem to serve as a valid initial guide in order to understand the kinematics and biomechanics of different squat variations.

Keywords: Squat Variations; Front Squat; High-Bar Back Squat; Low-Bar Back Squat; Barbell Squat.

Introduction

The squat is generally regarded as a valid and reliable measure of lower body/core strength and functional power. Furthermore, it is considered a standard exercise for increasing lower extremity maximum strength [1-3]. It has therefore found its way into many areas of strength and conditioning training and is indispensable in most sports due to its versatility and functionality [4]. For athletes who perform running, sprinting or jumping movements, the squat is particularly relevant because it trains the most important muscle groups (m. rectus femoris, m. gluteus maximus, m. biceps femoris, m. semitendinosus, m. triceps sure) required for these movements [5,6]. Moreover, due to its biomechanical and neuromuscular characteristics that are similar to a wide variety of athletic movements, the squat is incorporated into numerous routines designed to improve athletic performance [7-10]. There are a total of three basic bilateral squat variations where a barbell is placed on the shoulders: the High-Bar Back-Squat (HBBS), the Low-Bar Back-Squat (LBBS) and the front squat (FS). Research into the biomechanics and/or kinematics of the classic bilateral barbell squat has mainly focused on the HBBS [11-31]. Fewer scientific publications examine the differences between HBBSs and LBBSs [32-44]. There is only a limited number of

published studies on the biomechanical and/or kinematic differences between the HBBS and the FS [45-54] that showed contradictory results regarding net joint moments and muscle activity [53]. In addition, to the best knowledge of the author, no scientific publication to date is exclusively devoted to comparing LBBSs and FSs. Only one study by Fry et al. [55] investigated the kinematic differences between all three variations within a single study, and another investigation examined the kinematic differences of FS and back squats, yet allowing the subjects to

freely choose between the HBBS and LBBS [51]. The following review summarizes the findings of all relevant studies detected which address the differences between FSs, HBBSs, and LBBSs, thereby allowing practitioners, trainers, therapists, and athletes to choose the variation most appropriate for achieving their respective goals.

Material and Methods

The research strategy was designed to include all possible indexed articles referring to the differences and similarities between the HBBS, LBBS and FS. Online databases providing extensive scientific literature of sport scientific and sport medical research, including PubMed, SPORTD iscus and Google Scholar, were screened for referenced articles from their publication date until May 2023. All databases were independently searched and vetted with the following string of search terms: "squat AND biomechanics", "squat AND kinematics" "squat variations AND biomechanics", "squat variations AND kinematics", "front squat", "high-bar squat", "high-bar back squat", "low-bar squat", "low-bar back squat", and "squat variations" and reviewed for inclusion. Only peer-reviewed German and English studies on bilateral barbell squat variations using the classic barbell were included in the review. All studies unrelated to bilateral barbell squat variations with the classic barbell, such as safety-bar squats, were excluded. The relevant information for differentiating and analyzing HBBSs, LBBSs and FSs was extracted from the included studies and comprehensively summarized.

Results

HBBS:

There are significant kinematic, kinetic and biomechanical differences between the three basic variations of the barbell squat [34,55]. The most common variation of the barbell squat is the HBBS, also known as traditional squat or Olympic squat [37]. When performing a HBBS, the barbell is placed on the upper part of the trapezius muscle directly under the spinous process of the 7th cervical vertebra (C7) [33]. It is considered a compromise between the hip-dominant LBBS (Figure 1, left) and the knee-extensor dominant FS (Figure 1, right) [56]. Different barbell positionings manifest in a shifted center of mass [34]. As a result, the movement patterns are adapted to ensure that the center of mass stays within the base of support while performing different squatting movements in order to maintain stability (Swinton et al., 2012). The more anteriorly the weight is positioned, the more erect the upper body can be during a squat [55,56], which consequently affects the moment arm ratio between the hip and knee joints (Figure 1, M1 and M2). From a kinematic point of view, the HBBS presents a balanced variation with a trunk segment (TSA) angle of 46.3 ± 4.8 as compared to the FS (with a more upright upper body (TSA: 63.6 ± 4.2) and the LBBS (with a more forwardly inclined torso (TSA of 40.7 ± 5. 8) [55]. The HBBS also requires less ankle-dorsiflexion than the FS at the same squatting depth, which is a relevant benefit for many athletes [56]. Therefore, the HBBS is usually the first variation to master after learning the bodyweight squat and before practicing its derivatives [4]. Even though LBBSs typically permit athletes to lift heavier weights, the HBBS remains one of the most essential exercises in athlete training [41], as it is characterized by an increased amount of knee flexion, a decreased amount of hip flexion, a more upright torso, and a deeper squatting position compared to HBBSs [37,44,57]. Moreover, deep HBBSs are an efficient exercise for preventing injuries and strengthening the lower extremities, provided that a proper technique is learned under the supervision of a professional [57]. Contrary to widespread belief, deep barbell squats do not increase the risk of injury of passive tissues [57]. Furthermore, recent research suggests that including deep squats to a preventative training program may be advantageous for reducing deficits prevalent among females and lowering the injury incidence [58].

LBBS:

During the LBBS the barbell is placed slightly lower on the rear deltoid in comparison to the HBBS (Figure 1, left). This also causes the elbows to rotate further back, although they remain in close proximity to the barbell's plane of motion [42]. The LBBS is typically performed by powerlifters and particularly recommended when the primary objective is to lift as much weight as possible [39]. By situating the barbell lower on the back, the LBBS

Reduces the moment arm in key anatomical compartments and leads to improved biomechanical working conditions for the hip extensor muscles, ultimately permitting the use of heavier weights during the squat [33,37,42]. As a result of the greater upper body tilt, the torque in the hip joint (Figure 1, left, moment arm 2) and the muscle activation of the hip extensor muscles increase as compared to the other barbell variations [20,34,41]. Moreover, LBBSs are characterized by increased hip flexion and, thus, allow for a greater forward inclination of the upper body [44,37,57,55]. Because of this, the LBBS seems to be the most effective variation if the goal is to squat a maximum load, as it is the case in powerlifting competitions [33,39,42,59]. Furthermore, if the objective is to primarily strengthen the posterior-chain hip muscles involving the hamstring, gluteal and erector spinae muscle groups, LBBSs are the most recommended barbell squat variation [37].

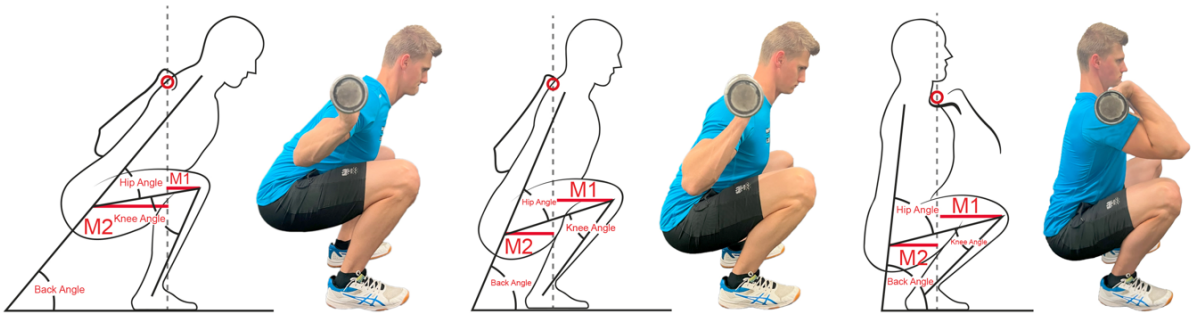

Figure 1: LBBS, HBBS and FS The knee moment arm (M1) to hip moment arm (M2) ratio is influenced by the barbell placement. Edited with friendly permission of the Aasgaard Company [69].

FS:

The FS is the third variation of the classic bilateral barbell squat. In contrast to the other variations, the barbell is not placed on the back but at the front of the shoulders (deltoid muscle) (Figure 1, right). Due to this barbell position, the FS requires a more upright upper body position, a greater TSA [37,53,55] (Figure 1, right) and it activates the knee extensor muscles more than the HBBS [37]. Due to the more upright body position [46,47], the increased anterior knee displacement and the consequently higher external torque in the knee joint (Figure 1, right, moment arm 1) [56], the FS is a very knee extensor dominant variation that activates the knee extensors more than the HBBS [56]. The m. quadriceps femoris muscle is therefore more activated than in other squatting variations [49,60]. However, there are several studies that indicate similar knee extensor demands, muscle activation and kinematics of the FS and HBBS [45,46,48,51,53,54]. This can be explained by varying loads as well as a comparatively small difference in load placements between the HBBS and FS, allowing individuals to modify their postures in order to put comparable external loads on their lower body [53]. Moreover, a comparison of the FS and HBBS load-velocity profiles revealed no distinctions between the two variations [52]. Although less absolute and relative load can be used in the FS than in back squat variations [2,48,61,62], recent research suggests that the FS can achieve a similar stimulus as the HBBS in terms of muscle activity, strength development and hypertrophy [48,63]. Moreover, the FS should be a foundational exercise for Olympic weightlifters since it trains the body position for the catch in the FS, which is a performance-critical factor when performing the clean [64,65].

The FS allows for a deeper squatting position and requires an increased knee flexion, less hip flexion and a more erect torso as compared to the HBBS and LBBS [56]. This may be an advantage compared to the LBBS, where there is less knee flexion [33]. This is because deep squat variations like the deep HBBS and the deep FS offer multiple benefits including greater muscle activation and increased athletic performance [66-68]. Therefore, it might be advisable to include a squat variation which can be performed to full knee flexion, such as the deep FS or deep HBBS, into the training routine.

Discussion

The purpose of this study was to review the literature on the biomechanical and kinematic differences between three prominent variations of the barbell squat: the HBBS, the LBBS, and the FS. Only one study that compares the kinematic differences between the three squat variations could be identified [55]. To the best knowledge of the author, despite the popularity of the squat, no study directly compared the biomechanical differences of the

LBBS, HBBS and FS. Simple 2D models, as illustrated in Figure 1 and applied by Rippetoe & Kilgore [69], can serve as an initial guide in order to understand the kinematics and biomechanics of different squat variations and deliver comparable results to 3D motion capture when assessing lower extremity movement [70]. However, 3D movement analysis is regarded as the gold standard for motion capture and analyzing kinematics [71]. Further research comparing and analyzing the biomechanics and kinematics of the three most important bilateral barbell squat variations should be conducted to enhance the understanding of their respective effects on muscle activation, joint loading, and overall performance. Above all, a study which compares the biomechanics of all three variations as well as a study which exclusively compares the LBBSs to the FSs are still lacking. Fry et al. [55] analyzed the kinematic dimension of the squat variations and in the study of Kasovic et al. [51] only two subjects performed a LBBS. A comprehensive investigation could help to reveal more valuable insights into the optimal squat variation for specific training goals, such as muscle hypertrophy, strength development, or injury prevention. By knowing more about how to appropriately incorporate each variation, individuals can improve their muscular development as well as their strength level and enhance their performance in a variety of strength-based activities.

Conclusion

In conclusion, each barbell squat variation is characterized by a distinct positioning of the barbell, which results in different biomechanical characteristics, including muscle activation, joint torque, and body position. The HBBS, with the barbell placed on the upper trapezius muscle, offers a compromise between the hip-dominant LBBS and knee-extensor dominant FS and is a fundamental exercise and a good starting point for beginners. The LBBS, during which the barbell is positioned lower on the posterior deltoid, should be favored if maximizing weightlifting performance is the primary objective. The FS variation is different to the other techniques in that the barbell rests on the front shoulders, resulting in a more upright upper body position. This variation engages the knee extensors to a greater extent than the other variations and is essential for athletes performing the clean, because it trains the necessary body position for a successful catch.

Author Contributions

Conceptualization GI; Methodology GI; Software GI; Validation GI; Formal Analysis GI; Investigation GI; Resources GI; Data Curation GI; Writing-Original Draft Preparation GI; Writing-Review and Editing; Visualization GI; Supervision GI; Project Administration GI; The Author has Read and Agreed to the Published Version of the Manuscript.

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