Article

A Biomechanical Comparison between Squatbar® and Olympic Barbell

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Abstract: When performing the traditional barbell back squat, athletes may experience discomfort in the shoulders or be limited by shoulder mobility. The Squatbar® is a barbell designed to be ergonomic to the shoulders but has never, in the scientific literature, been compared to the traditional Olympic barbell. Thus, the current study investigated kinematics, kinetics, and myoelectric activity (EMG) between the Squatbar® barbell and the Olympic barbell when performing a one-repetition maximum (1-RM) back squat. Twelve strength-trained men (body mass: 83.5 ± 7.8 kg, age: 27.3 ± 3.8 years, height: 180.3 ± 6.7 cm) performed a 1-RM squat with both the Olympic and Squatbar® barbells. The paired samples t-test revealed significantly more weight was lifted with the Olympic barbell compared to the Squatbar® barbell (148 ± 21 kg vs. 144.5 ± 20 kg) and was accompanied by greater shoulder external rotation ($74 \pm 7.5°$ vs. $59.6 \pm 9.2°$). No differences in joint kinematics of the lower limbs, kinetics, or EMG were observed between the two barbells. The results of the current study indicate the Squatbar® to be a suitable substitution for the Olympic barbell for athletes with reduced shoulder mobility when performing the squat. It was concluded that the Squatbar® induces similar kinetics, kinematics, and EMG when compared to the Olympic barbell, except for reducing external rotation of the shoulder.

Keywords: barbell; squat; kinematics; kinetics; EMG

1. Introduction

Resistance training is important for general health [1] and increasing physical capacity, thus, improving performance in a sporting context [2–4]. Three exercises commonly performed by both athletes and the general public are the squat, bench press, and deadlift as these exercises are multi-joint movements that train a large proportion of the body. The sport of powerlifting consists of the aforementioned three movements, whereby the athlete seeks to lift as much weight as possible for one repetition (1-RM) [5,6]. In recent years, the popularity of the sport of powerlifting has increased for both sexes across different competitive levels. As performance in competition is a result of the weight lifted in these three exercises, specific training prior to competition can become repetitive. The repetitiveness can result in overuse injuries, while acute injuries may occur due to the specific demands of lifting heavy weights [7].

All three movements involve a large amount of muscle mass contracting to lift heavy loads, which exposes the athlete to high demands. Although injury rates in powerlifting are low in comparison to contact sports [8–10], in a study based on 245 powerlifting athletes as many as 45% of the participants reported problems during their workout routines. The knees, shoulders, and lower back are the body regions where injuries are most frequently reported [11]. Pain and discomfort may negatively affect training and are considered a problem for powerlifters, and have been suggested to be related to factors such as inappropriate lifting technique and lifting with the joints towards their end range of motion [5].

The traditional squat requires coordinated flexion of the hips, knees, and ankles when descending prior to extension during the upwards phase, to return to the initial position [12]. If performed appropriately, the squat is considered a safe, functional movement with transfer to both sports performance and daily living [13], which has sparked interest in the investigation of the mechanics of the squat [14]. However, it is not uncommon that people are unable to perform the traditional back squat, leading to alternative methods of training for the movement pattern, which may alter the technical requirements [14]. Populations experiencing pain or reduced mobility in the lower back, knees, or shoulders during traditional back squatting have led to the search for pain-free exercises with similar benefits, as other movement patterns of the lower limbs (e.g., leg press) may provide less transfer to functional performance [15].

For example, coaches may implement different barbells (e.g., safety bar) as an alternative to the traditional barbell back squat to reduce stress on the lower back [14], although training the variations may affect 1-RM performance in the traditional barbell back squat due to different technical requirements [13,16], which could be detrimental to athletes competing in strength sports. As performance in powerlifting is determined by 1-RM, athletes often perform the squat with a low-bar placement, which for many athletes is beneficial [17,18]. However, the back squat challenges shoulder mobility [19], especially when the bar is placed further down the spine in a low-bar squat.

A special barbell that is suggested to enhance squat ergonomics of the shoulders is the Squatbar®, which is a barbell with curved handles that are designed to reduce the external rotation of the shoulders (Figure 1A). Anecdotal observations indicate that athletes experience less shoulder discomfort when using the Squatbar® in comparison to the traditional Olympic barbell (Figure 1B). However, to the authors' knowledge, the mechanics when performing the squat with these two barbells have never been compared in the scientific literature. Despite anecdotal evidence, such a comparison is important for deciding the similarities/differences in technical requirements. Such an investigation could provide information regarding the usefulness of the Squatbar® for accumulating training volume for athletes struggling with mobility issues in the shoulders, while still being specific in the technical requirements of the competition lifts. This information is especially relevant to powerlifters, who may additionally aggravate their shoulders by high-load training on the bench press [7]. Thus, the objective of the current study was to investigate kinematics, kinetics, and myoelectric activity (EMG) between the Squatbar® barbell and the Olympic barbell when performing a 1-RM squat. It was hypothesized that squatting with a Squatbar® barbell would require less shoulder external rotation compared to the Olympic barbell, with similar kinetics, EMG, and joint kinematics of the lower limb.
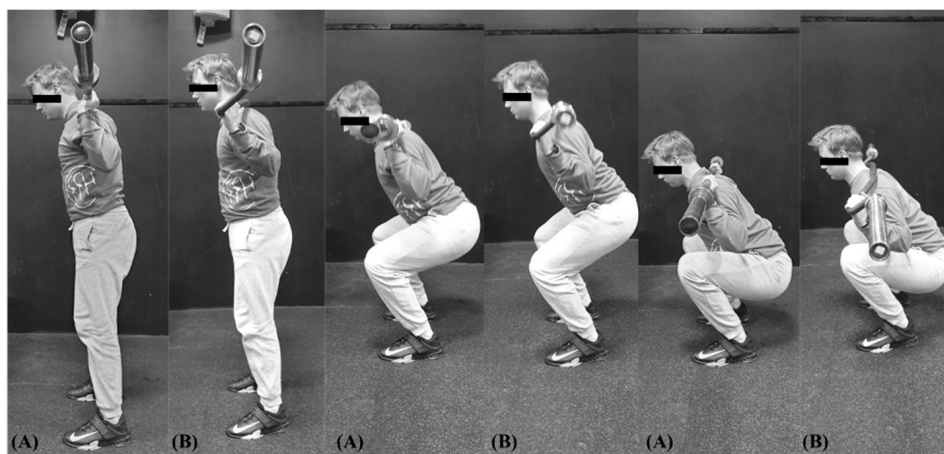

Figure 1. Illustration of the traditional Olympic barbell (**A**) and Squatbar® (**B**) when performing a squat.

2. Materials and Methods

To investigate the difference in squat kinetics, kinematics, and EMG between the Squatbar® (SQUATBAR, Norletic AS, Stord, Norway) and traditional Olympic powerlifting barbell (Rogue, Ohio power bar), a randomized within-subject design was utilized. The dimensions for the Squatbar were as follow: 20 kg, 2.17 m end-to-end distance, the start of the curved grip-handle was inserted at 90° (0.495 m from center) perpendicular to the barbell, whereby the end of the grip-handle was inserted at 142.9° (0.2 m from center). The Olympic barbell had the following dimensions: 20 kg, 2.2 m end-to-end distance, and 0.685 m from the center to the start of the shaft. Both barbells were 0.028 m in diameter.

2.1. Participants

The participants in the current study consisted of 12 recreationally strength-trained men (body mass: 83.5 ± 7.8 kg; age: 27.3 ± 3.8 years; height: 180.3 ± 6.7 cm), who were able to back squat 1.5 × their body mass in external load with a technique conforming to the criteria set by the International Powerlifting Federation (IPF) [20], which includes a depth requirement (Figure 2A). The participants who volunteered to participate were recruited from a local commercial gym and had to declare an absence of injury, sickness, or any other illness that could negatively affect performance. The testing protocol was explained both orally and in writing, with written consent that had to be signed prior to participation. The study was in alignment with the latest revision of the Declaration of Helsinki and approved by the local ethics committee and Norwegian Centre for Research Data, project number: 701688.
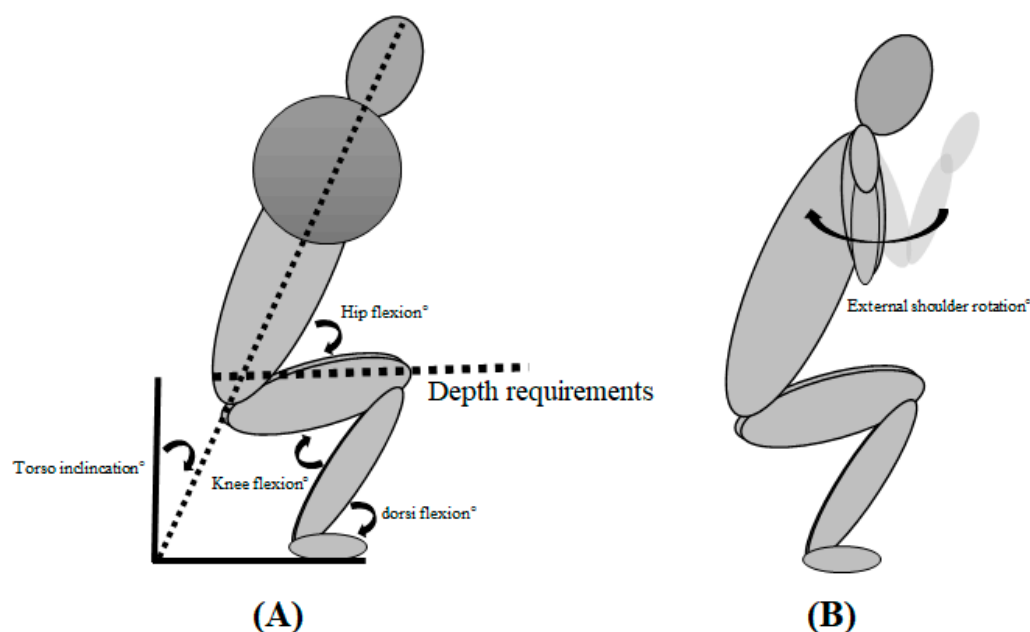

Figure 2. Definition of joint angles (**A**,**B**) and depth requirements.

2.2. Procedure

To increase ecological validity, the participants self-selected barbell placement, stance width, and external rotation of the feet measures. However, the barbell placement and positioning of the feet were standardized for all attempts with both barbells. To ensure that depth in the bottom position was in alignment with the IPF standard (hip vertically below the knee), an elastic band marked the bottom position, which the participant had to touch with his hamstrings prior to initiating the concentric phase.

Testing started with the participants' height being measured with a measuring tape, while weight was taken by a standing scale (Soehnle Professional 7830, stand scale). Afterward, a specific warm-up was initiated with the barbell being tested by performing

sub-maximal lifts at a percentage relative to 1-RM [21], before attempting a 1-RM. Loads were increased until reaching concentric failure, to assure the validity of displaying a true 1-RM. When 1-RM was established, a re-warm-up at sub-maximal intensities was initiated for the other barbell, before establishing 1-RM in a similar manner. The first barbell being tested was randomized, and equally weighted (6 for the Squatbar vs. 6 for the Olympic barbell) to reduce the chance of the testing order confounding the outcomes. A minimum rest of 4 min was required between each maximal attempt, whereby safety was assured by two strength and conditioning professionals spotting the athlete at each side of the barbell.

2.3. Measurements

EMG was sampled by Trigno Avanti sensors (DELSYS, Natick, MA, USA) sampling at 1111 Hz and placed on the participant's dominant side for 15 different muscles (trapezius pars ascendens, transversus and descendens, rectus abdominis, erector spinae iliocostalis, erector spinae longissimus, gluteus maximus, gluteus medius, rectus femoris, vastus lateralis, vastus medialis, semitendinosus, biceps femoris, gastrocnemius medialis, and soleus medialis). Prior to the attachment of the EMG equipment, the skin was prepared to reduce noise and skin impedance, which involved shaving, rasping until the skin turned light red, and cleaning with alcohol. Afterward, EMG equipment was placed in the presumed direction of the underlying muscle fibers, in accordance with the SENIAM recommendations [22].

EMG was synchronized with a 3D motion capture system (Qualisys, Gothenburg, Sweden), whereby 8 cameras recording at 500 Hz track reflective markers placed on anatomical landmarks, allowing sampling of peak joint kinematics (shoulder, hip, knee, and ankle joint angles). The placement of markers was based on earlier research [23], and were placed on both sides of the body (radial- and ulnar styloid, lateral- and medial epicondyle of the humerus, posterior- and anterior superior iliac spine, C7 spinous process of the vertebra, acromion, thoracic process 1 of the vertebra, midpoint between the lower angles of the scapulae, sternum xiphisternal and jugular notch joint, femoral lateral and medial epicondyle, 1st and 5th proximal phalanx, and lateral and medial malleolus. The motion capture system was also utilized to sample barbell kinematics (barbell time and velocity concentrically/eccentrically, and barbell displacement). The data sampled from EMG and Qualisys were converted to C3D files and exported to Visual 3D v6 (C-motion, Germantown, MD, USA), whereby EMG was high- and low-pass-filtered (20, 500 Hz) to minimize noise induced from external noise [24]. EMG data were fully wave-rectified and calculated as root-mean-squared over the concentric phase and used for further analysis.

Sagittal plane joint angles (hip: torso-thigh segments, knee: thigh-leg segments, and ankle: leg-foot segments) were defined as 0° in a standing upright position and increased with increased joint flexion (Figure 2A). Lean of the torso was defined relative to the lab, whereby a greater lean forward corresponds to an increased angle.

Incorporation of the Qualisys motion capture system with two force plates (AMTI Multi-axis Force Transducer BP6001200–2000, Lexington, KY, USA; Kistler force plate, type 9260AA6, Winterthur, Switzerland) was utilized to trace the three-dimensional ground reaction forces and facilitate the calculations of inverse dynamics. To calculate joint kinetics, motion capture data, and force data were exported to Visual 3D v6 software (C-motion, Germantown, MD, USA), where all inverse dynamics were calculated with compute model-based data, following a similar procedure to that used by Larsen, Kristiansen, Nygaard Falch, Estifanos Haugen, Fimland and van den Tillaar [21]. Moreover, all computations were smoothed with a lowpass Butterworth filter at a cutoff frequency of 6 Hz. Joint angles were calculated in the distal to proximal orientation with a Cardan sequence order at x–y–z. Hip, knee, and ankle joint moments were calculated using inverse dynamics calculations in a resolute coordinate system. The joint moments were internal net joint moments, expressed as mean and standard deviations, with respect to the resolute coordinate system of the distal segments and summed for both left and right segments. Net joint moments were normalized to the body mass of the participant using default normalization and expressed

as Nm/kg. Mean and peak concentric extension moments for the ankle, knee, and hip joints were used for further analysis. For a more thorough description of the modeling procedure, see Larsen, Kristiansen and van den Tillaar [23].

2.4. Statistical Analysis

Based on earlier studies in squats [21,23,25], the minimum number of participants required was estimated by using G * Power 1 (version 3.1.9.6). The analysis indicated that at least 10 participants ($\alpha = 0.05$, $1 - \beta = 0.95$, Cohen's $d = 1.2$) were necessary. The data are reported as mean $\pm$ standard deviation. A paired samples t-test was conducted to compare the dependent variables (kinematics, kinetics, and EMG) between the two different barbells. Normality was controlled using the Shapiro–Wilk test, and if the assumption of sphericity was not met, the Greenhouse–Geisser correction was used to adjust the *p*-value. Effect size was calculated according to Cohen's *d*, whereby values of 0.01 to 0.2 were defined as very small, 0.2 to 0.5 as small, 0.5 to 0.8 as large, 0.8 to 1.2 as very large, 1.2 to 2 as very large, and >2 defined as huge [26,27]. The significance level was set at $p < 0.05$, and all statistical analyses were carried out using SPSS version 27 (IBM Corp., Armonk, NY, USA).

3. Results

Participants lifted significantly greater loads with the Olympic barbell (148 ± 21 kg) compared to the Squatbar barbell (144.5 ± 20 kg) ($t_{11} = 2.2$, $p = 0.03$, $d = 0.2$). No significant differences were found for barbell kinematics between the squat conditions ($t_{11} \leq 1.8$, $p \geq 0.07$, $d < 0.39$) (Table 1).

Table 1. Vertical barbell kinematics for the Olympic vs. Squatbar barbell.

	Eccentric Velocity (m/s)	Concentric Velocity (m/s)	Barbell Displacement (m)	Eccentric Time (s)	Concentric Time (s)
Olympic barbell	-0.37 ± 0.12	0.21 ± 0.06	0.63 ± 0.05	1.69 ± 0.42	3.01 ± 0.82
Squatbar barbell	-0.34 ± 0.11	0.23 ± 0.07	0.63 ± 0.04	1.83 ± 0.43	2.70 ± 0.78

Significantly greater shoulder external rotation was observed for the Olympic barbell in comparison to the Squatbar barbell ($t_{11} = 2.3$, $p = 0.02$, $d = 1.72$). No other differences in joint angles were observed between the squat conditions ($t_{11} \leq 0.3$, $p \geq 0.7$, $d < 0.05$) (Table 2).

Table 2. Peak joint angles in the Olympic vs. Squatbar barbells.

	Shoulder External Rotation (°)	Torso Inclination (°)	Hip Flexion (°)	Knee Flexion (°)	Dorsi Flexion (°)
Olympic barbell	74 ± 7.5 *	70.3 ± 8.4	108.8 ± 16.1	122.3 ± 7.9	13.0 ± 6.0
Squatbar barbell	59.6 ± 9.2	70.6 ± 9.2	106.9 ± 16.7	121.0 ± 7	12.7 ± 5.4

* Indicates a significant difference between the two barbells at a $p < 0.05$ level.

No significant differences were observed for mean or peak vertical ground reaction force ($t_{11} = 2.0$, $p = 0.06$, $d < 0.28$) or net joint moments between the squat conditions ($t_{11} \leq 1.9$, $p \geq 0.07$, $d < 0.38$) (Figure 3).

No significant differences were observed in EMG for any of the muscles (Figure 4) or the percentage of joint moment contribution to total moment between the squat conditions ($t_{11} \leq 1.6$, $p \geq 0.12$, $d < 0.27$) (Figure 5).
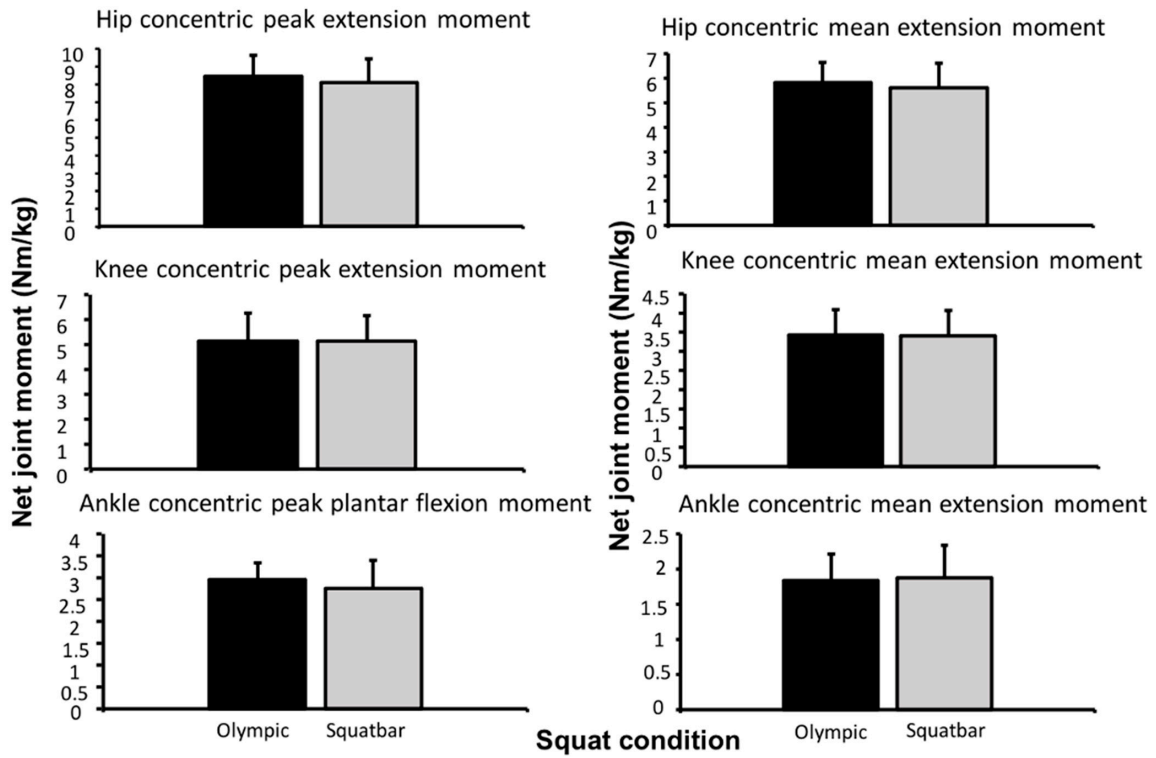
Figure 3. Net joint moments in the Olympic vs. Squatbar barbell.
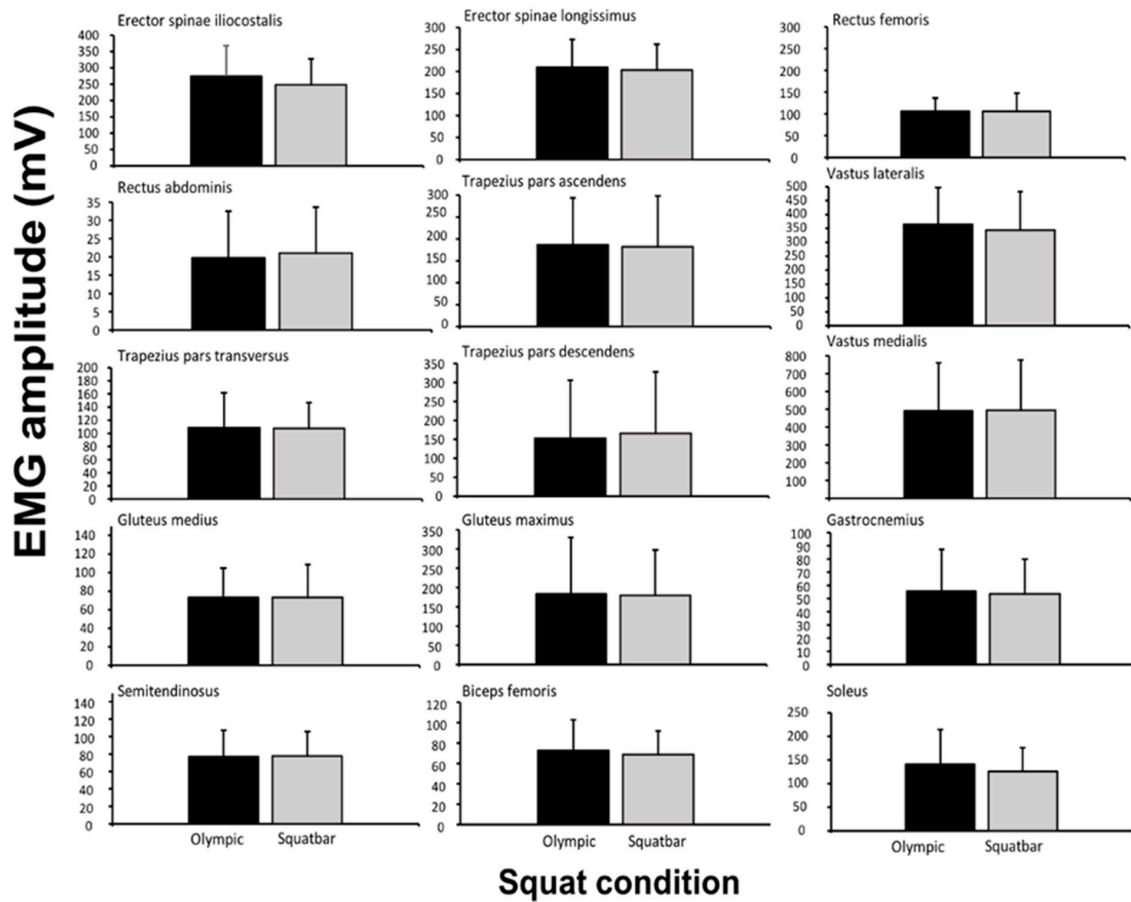

Figure 4. Mean (SD) EMG amplitude during the concentric phase for Olympic vs. Squatbar barbell (RMS).
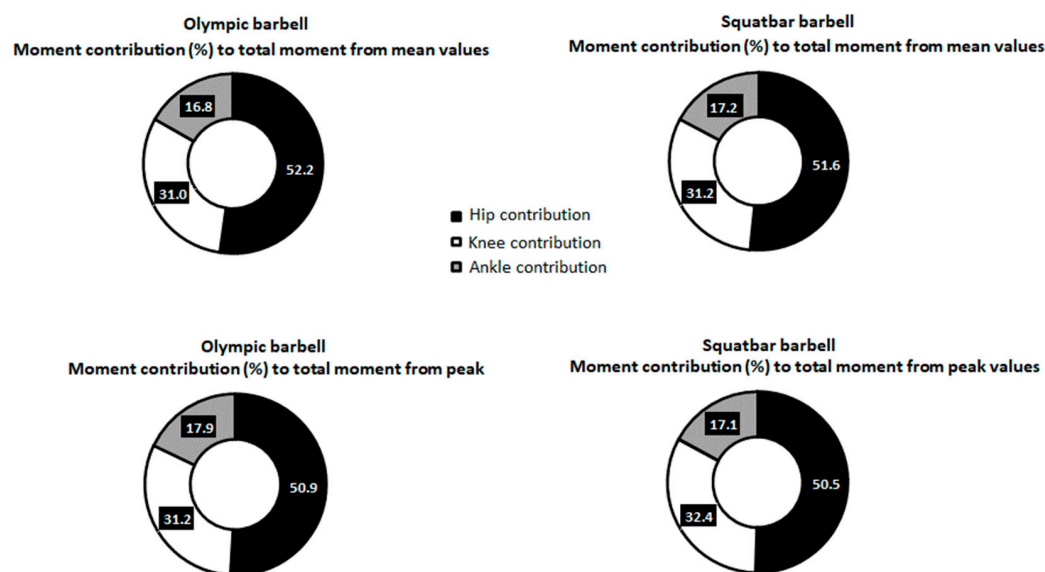
Figure 5. Percentage (%) mean and peak moment contribution for each joint to total moment.

4. Discussion

The current study investigated kinematics, kinetics, and EMG between the Squatbar[®] barbell and the Olympic barbell when performing a 1-RM squat. The main findings were that observed kinematics, kinetics, and EMG were similar between the two barbells, except that the Squatbar[®] revealed less peak external rotation of the shoulders with less external load lifted in the 1-RM.

The findings are in accordance with the study's hypothesis, except for the lower maximal amount of load lifted with the Squatbar[®], which might be a result of the design of the study. The participants were not familiarized with the Squatbar[®], while they have been regularly performing the squat with the Olympic barbell throughout their training career. As such, it could be speculated that the unfamiliarity with the new placement of the arms resulted in less load being lifted, as a result of psychological factors. The assumption is reasonable since the joint kinetics and EMG were similar in the 1-RM, thereby indicating similar requirements with the two barbells [28].

The observations suggest similar technical requirements for the two barbells, as velocity, joint kinematics and kinetics, the magnitude of force, and EMG were similar [28,29], indicating that the Squatbar[®] represents a sound alternative to the Olympic bar, in terms of neuromuscular specificity. This finding is important since specific powerlifting training consists of heavy loads to increase 1-RM. From an acute biomechanical perspective, squatting with a Squatbar[®] barbell may be an option to that with the Olympic barbell, which provides the same joint kinetics and kinematics and EMG, yet requires less shoulder external rotation, which is beneficial for athletes with shoulder mobility issues.

Despite a large number of exercises and barbells suggested as alternatives to the traditional back squat with an Olympic barbell, differences in biomechanics and EMG are often observed [12,14,18]. The safety squat bar has been suggested to be more ergonomic for the shoulders while requiring less inclination of the torso [14]. However, the safety bar might change the technical requirements of the squat movement. When comparing the Olympic barbell to the safety squat bar, Hecker, Carlson and Lawrence [14] observed an 11.3% difference in load at 3-RM, with 50% higher EMG in the trapezius, although EMG decreased in the hamstrings, vastus medialis, and gastrocnemius. Furthermore, a more upright torso was observed in the safety bar squat, accompanied by less hip flexion. Kristiansen, Larsen, Haugen, Helms and van den Tillaar [18] also observed a more upright torso inclination in the safety bar squat, accompanied by greater EMG in the gluteus maximus compared to high-bar squatting, and differences in knee-extensor moments compared to the low-bar squat. Based upon these findings [14,18], it could be assumed

that the technical requirements of the Squatbar® are more similar to those of the Olympic barbell compared to the safety bar. Other training variations have been postulated for training the squat movement in athletes with reduced shoulder mobility, such as front squat variations, which may also alter the technical requirements. The front squat induces lower compressive forces and knee-extensor moments [19], reducing specificity and possible transfer to 1-RM attempts with the Olympic barbell.

As such, for an athlete suffering from reduced shoulder mobility, the Squatbar®, from an acute biomechanical perspective, is indicated to be a good alternative for accumulating training volume in a movement pattern with similar requirements to the traditional barbell back squat with an Olympic barbell.

4.1. Limitations

This acute study is limited by not investigating long-term effects. Furthermore, the current study only compared 1-RM lifts, while strength training programs consist of sets at different repetitions and intensities. Furthermore, it is possible that the observed difference in external load lifted is a result of unfamiliarity with the Squatbar®, while EMG, kinetics, and kinematics were similar. Lastly, the comparisons made in this study are based on peak kinematics and net joint moments, along with mean EMG in the concentric phase. As such, there might be variations in kinematic, kinetic, and EMG variables within the different phases of the lift that this study did not account for.

4.2. Practical Applications

The acute observations of the current study indicate the Squatbar® to be a sound alternative to the traditional Olympic barbell for athletes with reduced shoulder mobility since a difference was only observed in external shoulder rotation.

5. Conclusions

Based upon the results of the current study, the two barbells share similar technical requirements, except for a reduction in the external shoulder rotation when using the Squatbar®. The observations in EMG, kinetics, and kinematics indicate, thereby indicating that the Squatbar® is a suitable substitution for the Olympic barbell for athletes with reduced shoulder mobility when training to increase 1-RM strength in the parallel back squat.

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