EFFECT OF LOAD AND VARIOUS EQUIPMENT MODALITIES ON BACK SQUAT BIOMECHANICS IN ELITE POWERLIFTERS

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This study compared back squat biomechanics in elite powerlifters under various equipment and intensity manipulations. Eleven elite powerlifters performed back squats in the following conditions: belt only (Raw), belt and elastic band attached to the bar (Band), and competition attire consisting of a belt, knee wraps, and squat suit (Equipped). In Raw lifts, back angle and hip moment at minimum upward velocity increased as intensity increased. Maximum hip moment at minimum upward velocity was greater in the Raw compared to the Band lift. Back angle, total hip moment at the bottom position, and total knee moment at the minimum upward velocity was greater in the Equipped compared to the Raw lifts. Overall, the Band condition was biomechanically similar to the Raw lifts. However, the Equipped condition displayed substantial biomechanical differences compared to the Raw condition.

KEYWORDS: Kinetics, kinematics, elastic band, squat suit, knee wraps

INTRODUCTION: The squat is a popular lower extremity strength exercise performed among professional athletes as well as in recreational strength trainers. In the sport of powerlifting, the squat is one of three main exercises (in addition to bench press and deadlift).
External equipment is most often used during the squat in formal powerlifting. According to the rules of the International Powerlifting Federation (IPF), the lifter can wear a belt, knee wraps and a single-ply powerlifting suit. The suit will thereby resist hip flexion, and aid the internal hip moments generated by the hip extensor muscles. Blatnik and co-workers (2012) found that the peak power during a 90% of 1RM lift was 15% higher using a suit. Similarly, the elastic knee wraps will aid the knee extensors in the deep position as they will stretch. A previous study has suggested that the vertical impulse is 10% higher with the use of knee wraps (Lake *et al.,* 2012). Unfortunately, these measurements do not directly quantify the contribution of the equipment, as the joint moment generation is still unknown as well as any changes to technique (e.g., back angle). Additionally, the use of equipment is time consuming and may be uncomfortable. For this reason, elastic bands are commonly used for training. Several studies have suggested positive effects from using the elastic bands (Rhea *et al.,* 2009; Anderson *et al.,* 2008). Compared with equipped, the unloading is achieved at the bar rather than aiding the joint moment generation at the joint. Compared with the unequipped (Raw) squat, the elastic band is likely to move the “sticking point” higher in the range of movement due to the additional help in the low position. Hence, the Band squat may stimulate the lower extremity muscles more evenly throughout the full range of movement compared with the Raw squat. However, it is not clear to what degree using elastic bands will simulate the use of equipment or change joint kinematics/kinetics compared with Raw lifts.
To understand how load affects squatting technique, it is necessary to investigate the joint moment distribution between the knee and hip joint. Bryanton and coworkers (2012) investigated how joint moments changed in loads up to 90% of 1RM among female recreational lifters, and found a relative increase in internal hip extensor moments. However, it is not known to what degree these results are valid in a cohort of powerlifters at even higher intensities. It is furthermore unknown if any such changes are accompanied by changes in trunk forward lean.

It was therefore the aim of this study to compare joint kinetics and kinematics in three different conditions of lifting deep barbell squats: a) Belt only (Raw), b) Belt + Elastic band (Band) and c) IPF approved competition attire including belt, knee wraps, and a single ply squat suit (Equipped). Furthermore, we aimed to investigate how load affects the joint kinetics and kinematics in the Raw condition.

METHODS: Eleven of the highest ranked Norwegian powerlifters (10 male and 1 female) in the senior and junior categories were invited to participate in the study (Mean ± SD; age = 21.6 ± 3.1 years; height = 1.75 ± 0.05 m; body mass = 93.4 ± 22.4 kg; maximum raw back squat = 187.8 ± 39.3 kg). The Regional Ethics Committee approved the study and informed consent was obtained from all subjects.

Procedures and data collection: Participants were equipped with 43 markers on various anatomical sites (Figure 1). After an initial standardized warm-up and static calibration, the lifters followed a standardized progression (average of 7 sets prior to 1RM) up to their Raw one repetition maximum (Raw 1RM). Approximately five minutes of rest were given in between warm-up sets and max attempts. One IPF certified judge assessed the squat performance according to IPF rules (IPF Rules Book, 2011). Biomechanical data were collected during the last three lifts, approximately corresponding to 90%, 95% and 100% of the 1RM. Next, the bar was equipped with aid from elastic bands attached to the rack above on both sides. Two types of elastic bands were used in this study; a purple band (width: 3.8 cm; stiffness: 0.58 kg/cm) for those lifting less than 160 kg in their Raw 1RM lift and a stronger, green band (width: 5.1 cm; stiffness: 0.78 kg/cm) for those lifting more than 160 kg. Again, the lifters followed a standardized progression with four series up to the elastic band 1RM (Band 1RM). Only the 1RM lift was recorded. Finally, the athletes were equipped with their competition attire including belt, knee wraps, and the squat suit. The lifters used their own (weightlifting) shoes, with no socks, during all lifts. The lifters performed 80%, 85% and 90% of their estimated 1RM. Only their final lift was recorded.

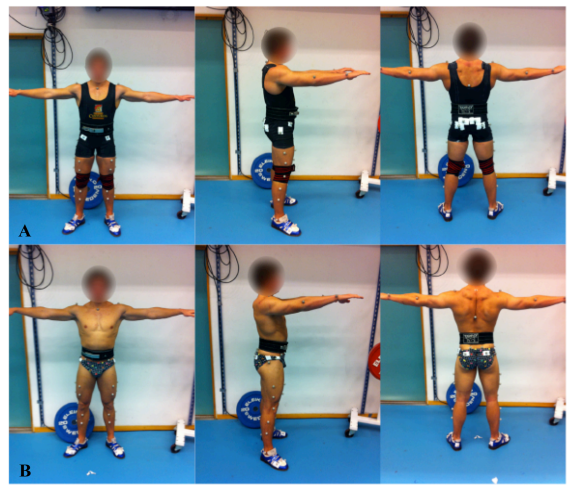

Figure 1: Maker placement in A) Equipped and B) Raw and Band conditions

Biomechanical calculations: Eight 300 Hz infrared cameras (ProReflex, Qualisys, Gothenburg, Sweden) recorded the movement of the 45 reflective markers (43 on lifters, 2 on barbell). The marker trajectories were tracked using the Qualisys Track Manager (Qualisys, Gothenburg, Sweden). Ground reaction force and center of pressure were recorded by two force platforms collecting at 1500 Hz (AMTI, Watertown, Massachusetts, USA). The marker trajectories and force platform data were imported into Matlab (MathWorks Inc., Natick, MA, USA) to calculate the kinetics and kinematics using custom scripts.

Marker trajectories and force data were both filtered and interpolated using Woltring's (1986) smoothing spline in the cubic mode with a 15 Hz cut-off frequency. Dynamic thigh and shank segment coordinate systems were found using an optimization procedure involving singular value decomposition (Soderkvist and Wedin, 1993). The knee joint center was defined according to the work of Davis *et al.* (1991), and the ankle joint center according to Eng and Winter (1995). The hip joint center was reconstructed based on the thigh marker cluster rather than the pelvic marker cluster, during the dynamic trials. The distance between the hip joint centers were constricted to the fixed distance that were determined from the static calibration recording (Bell *et al.,* 1990).

Hip and knee joint moments were calculated with inverse dynamics using recursive Newton-Euler equations of motion as described by Davis *et al.* (1991). We calculated the total net joint moment, i.e. without projecting onto the three rotational axes of the joint. The back angle was defined as the sagittal plane angle of the torso relative to the vertical axis. Squat depth was determined by the thigh angle relative to the floor. A negative thigh angle indicated that the hip joint was lower than the knee joint. The minimal ascending velocity (minimum velocity) was chosen to describe the "sticking point" during the concentric phase.

Statistical analyses: Pearson correlation coefficients were computed to assess the effect of load (i.e., intensity) on the dependent variables: back angle, hip and knee moments, and hip:knee moment ratio at the bottom position and minimum velocity during the Raw lifts. Mean differences between the Raw 1RM and Band 1RM as well as the Raw Low (91-96% 1RM) and Equipped dependent variables were assessed using a dependent samples *t*-tests (with effect size using Cohen's *d*).

RESULTS AND DISCUSSION: Due to technical problems, we had to exclude three subjects from the Band 1RM comparison, leaving 9 subjects for analysis. In the Equipped condition, six subjects were excluded due to technical problems or inadequate depth, leaving 5 subjects (and 4 for back angle comparison). As load increased, back angle (r =.52) and total hip moment (r =.42) at the minimum velocity increased as well as concentric phase duration (r =.79) and total lift duration(r = .67) (p < .05). No other significant associations were found as load increased. Raw 1 RM and Band 1 RM comparison results are located in Table 1. Raw low and Equipped comparison results are located in Table 2.

Table 1
Kinetic and Kinematic Comparison Between Raw and Band Conditions (N=9)

		Raw 1RM (*SD*)	Band 1RM (*SD*)	Cohen's *d*
Load (kg)		**184.0 (44.5)**	**217.1 (49.6)**	**-2.94**
Back Angle (°)	Bottom Position	45.2 (3.5)	46.6 (4.3)	-0.66
	Minimum Velocity	55.8 (4.6)	56.2 (5.4)	-0.13
Hip Moment (Nm)	Bottom Position	494.2 (152.9)	496.4 (156.9)	-0.06
	Minimum Velocity	**386.8 (83.3)**	**366.1 (76.7)**	**1.18**
Knee Moment (Nm)	Bottom Position	314.0 (76.7)	318.3 (87.7)	-0.08
	Minimum Velocity	166.9 (30.6)	173.6 (32.3)	-0.29
Hip:Knee Moment Ratio	Bottom Position	1.6 (0.3)	1.6 (0.2)	0.05
	Minimum Velocity	2.5 (0.4)	2.2 (0.4)	0.40
Thigh Angle (°)	Bottom Position	-5.5 (9.3)	-7.4 (10.1)	0.47
	Minimum Velocity	23.2 (8.8)	28.0 (5.4)	-0.75

Note. Bold values indicate a significant difference between conditions ($p \le .05$).

Table 2
Kinetic and Kinematic Comparison Between Raw and Equipped Conditions (N=5 and N=4 for Back Angle)

		Raw Low[#] (*SD*)	Equipped* (*SD*)	Cohen's *d*
Load (kg)		**172.4 (43.9)**	**242.8 (63.5)**	**-3.41**
Back Angle (°)	Bottom Position	**45.7 (1.9)**	**52.4 (5.6)**	**-1.58**
	Minimum Velocity	**51.0 (3.8)**	**54.6 (2.8)**	**-2.94**
Hip Moment (Nm)	Bottom Position	**488.2 (169.8)**	**570.1 (214.7)**	**-1.23**
	Minimum Velocity	357.0 (65.7)	391.6 (90.8)	-0.75
Knee Moment (Nm)	Bottom Position	329.5 (86.5)	339.1 (64.8)	-0.26
	Minimum Velocity	**165.3 (33.8)**	**228.3 (51.3)**	**-2.12**
Hip:Knee Moment Ratio	Bottom Position	1.5 (0.3)	1.7 (0.4)	-1.01
	Minimum Velocity	**2.2 (0.2)**	**1.8 (0.4)**	**1.21**
Thigh Angle (°)	Bottom Position	**-9.0 (12.5)**	**1.9 (6.6)**	**-1.83**
	Minimum Velocity	**23.4 (8.0)**	**31.8 (4.9)**	**-2.58**

Note.[#]Mean = 93.5, Range = 91-96% 1RM Raw; *Estimated 90% of Competition 1RM; Bold values indicate a significant difference between conditions ($p \le .05$).

Overall, as intensity increased the biomechanics at the bottom position remained similar. At the minimum upward velocity we saw a shift in relative loading towards higher hip extensor loading as intensity increased with a resulting forward lean (i.e., increased load on the back). Knee moments did not change as intensity increased from approximately 90-100% indicating the participants used their full potential in knee extensors at sub-maximal lifts.

The Raw 1 RM and Band 1 RM produced similar biomechanics with the exceptions of greater hip moments and potentially a lower thigh angle at minimum velocity (e.g. location of sticking point) in the Raw 1 RM, despite lower overall load. The Equipped condition displayed substantial loading and kinematic differences compared to Raw lifts. The knee wraps increased knee extension capability (e.g., approximately 38% higher knee moments in Equipped vs Raw lifts). Additionally, the suit likely influenced the hip extensor capabilities (e.g., approximately 17% higher hip moments in Equipped vs Raw lifts). Additionally, the suit (and potentially knee wraps) likely influenced the less upright posture and change in minimum velocity location. The resulting changes in trunk kinematics in the Equipped condition may cause in increase in spinal compression/loading compared to Raw and Band conditions.

CONCLUSION: The main difference in response to greater loading during Raw lifts at high intensities (e.g., >90%) is increased hip moments and greater trunk lean. Overall, maximum Band and Raw lifts were very similar biomechanically, with slight differences in hip moments and location of the sticking point. The competition equipment (e.g., suit and knee wraps) gave added support for hip extensors and adductors as well as knee extensors. The trunk angle was also less upright in the equipped compared to the Raw Condition. Additional modalities should be investigated which aim to emulate equipped lifting as the biomechanical stimuli is relatively different in Raw and Band aided lifts.

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