Acute effects of knee wraps/ sleeve on kinetics, kinematics and muscle forces during the barbell back squat.

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Abstract

PURPOSE: The aim of the current investigation was to comparatively examine the effects of knee wraps/ sleeves on kinetics, three-dimensional kinematics and muscle forces during the barbell back squat. *METHODS:* Fifteen male lifters completed squats at 70% of their 1 repetition maximum, in four different conditions (nothing, competition knee wrap, training knee wrap and knee sleeve). Three-dimensional kinematics were measured using an eight-camera motion analysis system, ground reaction forces (GRF) using a force platform and muscle forces using musculoskeletal modelling techniques. Differences between conditions were examined using one-way repeated measures ANOVA. *RESULTS:* The results showed that the integral of the quadriceps (nothing=58.30, competition=51.87 & training wrap=53.33N/kg·s), hamstring (nothing=39.01, competition=35.61 & training wrap=33.97N/kg·s), gluteus maximus (nothing=24.29, competition=22.22 & training wrap=21.03N/kg·s), gastrocnemius (nothing=7.25, competition=5.97 & training wrap=6.39N/kg·s) and soleus muscles (nothing=15.49, competition=12.75 & training wrap=13.64N/kg·s) during the ascent phase was significantly greater in the nothing condition compared to both knee wraps. In addition, whilst knee wraps and knee sleeves significantly improved perceived knee stability, perceived comfort was significantly reduced in the knee wraps and improved in the knee sleeve. *CONCLUSIONS:* Taking into account the reduced muscle kinetics, knee wraps may diminish lower extremity muscle development. Therefore, knee sleeves may be more efficacious for athletes who regularly utilize the back squat for their training goals, although further longitudinal analyses are required before this can be fully established.

Introduction

The back squat is perhaps the most frequently utilized resistance training exercise (1). Because of its ability to recruit the quadriceps, gluteal, hamstrings, tibialis anterior, triceps surae and lumbar muscles (2), it forms the basis of most strength and conditioning regimens (3).

Because heavy loads are typically borne during the back squat exercise, many athletes choose to perform their squat activities using external supports (4). Knee wraps and knee sleeves are commonly adopted by those involved in competitive and recreational resistance training (5). As described by Lake et al., (3), knee wraps are typically made from thick canvas with interwoven rubber filaments to provide elasticity. To be compliant with International Powerlifting Federation (IPF) regulations, knee wraps can be a maximum of 2m in length and should be wrapped as tightly around the knee as possible (3). Similarly, knee sleeves are characteristically made from a dense yet elasticated material such as neoprene in order to provide both elasticity and durability. To be compliant with International Powerlifting Federation (IPF) regulations, knee sleeves can be a maximum of 0.3m in length and should provide a high level of compression around the knee joint.

Knee wraps and sleeves are utilized to mediate a mechanical advantage during the back squat exercise (5). They are adopted by both competitive and recreational lifters in order to enhance performance during the squat exercise (3). During the eccentric (descent) phase of the back squat, the knee joint exhibits active flexion in order to lower the bar, allowing the elastic material which comprises the knee wrap/ sleeve to deform (6). When the device is deformed, elastic energy is stored within the bonds between the atoms that make up the sleeve/ wrap.

This potential energy is released as kinetic energy during the concentric (ascent) phase of the lift, in a process known in strength & conditioning literature as carryover (6).

There has been surprisingly little research concerning the influence of knee wraps/ sleeves on the biomechanics of the squat. Lake et al., (3) examined the effects of knee wraps on biomechanical and performance parameters at 80% of 1 repetition max (1RM) during the barbell back squat. Their findings showed that horizontal bar displacement was significantly reduced, the lowering phase was performed significantly faster and peak power was significantly greater when wearing knee wraps. This led Lake et al., (3) to conclude that knee wraps enhanced mechanical output but altered the squat technique in a manner that may affect the target musculature and possibly diminish the integrity of the knee joint. Gomes et al., (6) examined the effects of knee wraps on muscle activation (EMG) and joint kinematics at 60 and 90% of back squat 1RM. Their findings showed that vastus lateralis activation was significantly greater at 60% 1RM but significantly reduced at 90% 1RM when wearing knee wraps. There was also a significant increase in gluteus maximus muscle activity when wearing knee wraps but only at 60% 1RM, and a significant increase in peak knee flexion at both 60 and 90% 1RM. Gomes et al., (5) examined the effects of hard and soft knee wraps on the peak vertical ground reaction force (GRF) produced during an isometric squat. This study showed that peak vertical GRF was significantly greater in both hard and soft knee wraps compared to performing without wraps. Finally, Marchetti et al., (4) analysed the influence of two different techniques of knee wraps placement (spiral where the wrap is placed on the knee in a circular fashion and X where the wrap is placed in a crossover fashion) on peak vertical GRF and rating of perceived exertion during an isometric barbell back squat. Their findings showed that although peak vertical GRF was greater in both techniques compared to performing without knee wraps, there were no differences between spiral and X conditions.

Despite the aforementioned scientific outputs concerning the effects of knee wraps/ sleeves on the biomechanics of the barbell back squat, there has yet to be any scientific investigation that has concomitantly examined the effects of knee wraps/ sleeves on the kinetics, three-dimensional kinematics and muscle forces of the barbell back squat. Therefore, such an investigation may provide further insight regarding the effects of knee wraps/ sleeves on biomechanical outcomes during the barbell back squat. As such, the aim of the current investigation was to comparatively examine the effects of knee wraps/ sleeves on kinetics, three-dimensional kinematics and muscle forces during the squat.

Methods

Participants

Fifteen male (age: 23.00 ± 3.47 years, stature: 181.93 ± 7.25 cm, mass: 85.83 ± 17.10 kg and 1RM back squat: 122.62 ± 24.43 kg) participants took part in the current study. Participants were all practiced in the high bar back squat with a minimum of 2 years of experience in this lift. All were free from musculoskeletal pathology at the time of data collection and provided written informed consent. All procedures performed were in accordance with the ethical standards of the institutional (STEMH ethical committee REF=458) and with the 1964 Helsinki declaration.

Knee wraps/ sleeves

Four experimental conditions were examined as part of the current investigation; nothing, knee sleeve, competition wrap and training wrap. The knee sleeve (Strength Shop, Inferno), was made of Neoprene with a thickness of 0.007m and length of 0.30m in line with IPF regulations. The sleeve came in four different sizes; small, medium, large and extra-large to accommodate all participants. The competition (SBD apparel, Knee Wraps, Competition) and training (SBD apparel, Knee Wraps, Training) wraps had a length of 2m and width of 0.08m in compliance with IPF regulations. The same researcher positioned the knee wraps as tightly as possible before each trial. After completion of their data collection, in accordance with Sinclair et al., (7), each participant subjectively rated each sleeve/ wrap in relation to performing in the nothing condition in terms of stability and comfort. This was accomplished using 3 point scales that ranged from 1 = improved comfort, 2 = no change and 3 = reduced comfort and 1 = improved stability, 2 = no change and 3 = decreased stability. Finally, the participants were also asked to subjectively indicate which of the four conditions that they preferred to perform their squat activities in.

Procedure

Three-dimensional kinematics were captured using an eight-camera motion analysis system (Qualisys Medical AB, Goteburg, Sweden) which sampled at 250 Hz. In addition, to capture GRF data piezoelectric force plates (Kistler, Kistler Instruments Ltd., Alton, Hampshire) were adopted, which collected data at 1000 Hz. Kinematics and GRF information were synchronously collected using an analogue to digital interface board.

Body extremity segments were modelled in 6 degrees of freedom using the calibrated anatomical systems technique (8), using a marker configuration utilized previously to quantify the biomechanics of the squat (9). The anatomical frames of the torso, pelvis, thighs, shanks and feet were delineated via the retroreflective markers described by Sinclair et al., (9). Carbon-fiber tracking clusters comprising of four non-linear retroreflective markers were positioned onto the thigh and shank segments. In addition to these the foot segments were tracked via the calcaneus, first metatarsal and fifth metatarsal, the pelvic segment using the PSIS and ASIS markers and the torso via C7, T12 and xiphoid process. Finally, a further two markers were positioned at either end of the bar. The centres of the ankle and knee joints were delineated as the mid-point between the malleoli and femoral epicondyle markers (10, 11), whereas the hip joint centre was obtained using the positions of the ASIS markers (12).

Static calibration trials (not normalized to static trial posture) were obtained with the participant in the anatomical position in order for the positions of the anatomical markers to be referenced in relation to the tracking clusters/markers. A static trial was conducted with the participant in the anatomical position in order for the anatomical positions to be referenced in relation to the tracking markers, following which those not required for dynamic data were removed. The Z (transverse) axis was oriented vertically from the distal segment end to the proximal segment end. The Y (coronal) axis was oriented in the segment from posterior to anterior. Finally, the X (sagittal) axis orientation was determined using the right-hand rule and was oriented from medial to lateral.

Squat protocol

For data collection, all participants presented to the laboratory 48 hours after their previous lower-body resistance training session. Before the measured squats were initiated, a general warm up was completed, followed by squat warm-up sets with 30 and 50% of 1RM (13). Participants completed five continuous high bar back squat repetitions at 70 % of their 1RM, in each if the four experimental conditions using a counterbalanced order. Participants reported their 1RM in the absence of wraps/ sleeves, as the aim was to delineate the maximum squat capacity without aid. A rest period of 3 minutes was enforced between each lift (3). A load of 70% of 1RM was selected in accordance with Sinclair et al., (14) and was deemed to be representative of a typical training load, whilst still maintaining the levels of repeatability necessary obtain a representative data set. In accordance with the NSCA guidelines, lifters were instructed to descend in a controlled manner to femur parallel, keep both feet flat on the floor, preserve proper breath control and maintain a constant/ stable pattern of motion for each repetition. Each participant was examined visually by an NSCA certified strength and conditioning specialist.

Processing

Marker trajectories were digitized using Qualisys Track Manager and then exported as C3D files. Kinematic parameters were quantified using Visual 3-D (C-Motion Inc, Gaithersburg, USA). Marker data was smoothed using a low-pass Butterworth 4th order zero-lag filter at a cut off frequency of 6 Hz (15). Kinematics of the hip, knee, ankle and trunk were quantified using an XYZ cardan sequence of rotations and joint moments using newton-euler inverse dynamics. All data were normalized to 100% of the squat via the first and second instances of maximal hip flexion (15). A further time point at the mid-point of the lift that separated the descent and ascent phases was identified using the lowest position of the bar (3). Three-dimensional kinematic measures from the hip, knee, ankle which were extracted for statistical analysis were 1) peak angle and 2) angular range of motion (ROM) from initiation to peak angle. In addition, sagittal plane measures from the trunk of 1) peak angle and 2) angular range of motion (ROM) were extracted. In addition to the above, the maximum velocity (m/s) of the barbell during the ascent phase was quantified, as was the maximum anterior displacement (m) of the barbell during the squat movement.

Quadriceps force was calculated using a musculoskeletal model (16). The quadriceps force was resolved by dividing the knee flexor moment from inverse-dynamics by the moment arm of the quadriceps muscle. The moment arm of the quadriceps was calculated by fitting a 2nd order polynomial curve to the knee flexion angle-quadriceps moment arm data presented by van Eijden et al., (16).

Hamstring, gluteus maximus, soleus and gastrocnemius forces were also quantified using musculoskeletal modelling approaches (17). The hamstring and gluteus maximus forces were calculated firstly using the hip extensor moment from inverse-dynamics and the hamstrings and gluteus maximus cross-sectional areas, which determined the extent of the joint moment attributable to each muscle (18). The hamstring muscle forces were then calculated by dividing the hip extensor moment attributable to each muscle by the muscle moment arms (19). The moment arms were obtained by fitting a 2nd order polynomial curve to the hip flexion angle-hamstrings/ gluteus maximus moment arm data of Nemeth & Ohlsen, (19). In addition, the gastrocnemius and soleus forces were calculated firstly by quantifying the ankle plantarflexor force, which was resolved by dividing the dorsiflexion moment from inverse dynamics by the Achilles tendon moment arm. The Achilles tendon moment arm was calculated by fitting a 2nd order polynomial curve to the dorsiflexion angle-Achilles tendon moment arm data of Self & Paine (20). Plantarflexion force accredited to the gastrocnemius and soleus muscles was calculated via the cross-sectional area of this muscle relative to the total volume of the triceps-surae (18).

All muscle forces were normalized by dividing the net values by body mass (N/kg). From the above processing, peak quadriceps, hamstring, gluteus maximus soleus and gastrocnemius forces were extracted for statistical analysis. In addition, the integral of these forces (N/kg·s) were calculated during the ascent and descent phases using a trapezoidal function. Finally, the peak rate of force development (RFD) at each of the quadriceps, hamstring, gluteus maximus soleus and gastrocnemius muscles during the ascent phase was also extracted by obtaining the peak increase in muscle force between adjacent data points using the first derivative function within Visual 3D (N/kg/s).

The maximum extent to which the knee joint centre moved anteriorly and laterally during the squat movement (m) was also calculated using Visual 3D. In addition, internal knee joint forces were also calculated in accordance with using the joint force function within Visual 3D (21). Furthermore, patellar tendon force was quantified using a model adapted from Janssen et al., (22). The knee flexion moment quantified using inverse dynamics was divided by the moment arm of the patellar tendon. The tendon moment arm was quantified by fitting a 2nd order polynomial curve to the knee flexion angle-patellar tendon moment arm data provided by Herzog & Read, (23). Patellofemoral stress was also quantified by dividing the patellofemoral joint reaction force, by the patellofemoral contact area. The patellofemoral reaction force was calculated by multiplying the adjusted quadriceps force (described above) by a constant which was obtained via the below equation [eq1] using the data of van Eijden et al., (16). Patellofemoral contact areas were obtained by fitting a 2nd order polynomial curve to the sex specific knee flexion angle-patellofemoral contact area data of Besier et al., (24).

[eq1] $$\text{constant} = (0.462 + 0.00147 * \text{knee flexion angle}^{2} - 0.0000384 * \text{knee flexion angle}^{2}) / (1 - 0.0162 * \text{knee flexion angle} + 0.000155 * \text{knee flexion angle}^{2} - 0.000000698 * \text{knee flexion angle}^{3})$$

The peak knee joint shear force, patellar tendon force, patellofemoral force (N/kg) and patellofemoral stress (KPa/kg) were extracted following normalization to body mass. The instantaneous loading rate of the aforementioned knee force (N/kg/s) and stress (KPa/kg/s) parameters was calculated by obtaining the peak increase force/ stress between adjacent data points using the first derivative function within Visual 3D. In addition, the integral of the aforementioned parameters (N/kg·s and KPa/kg·s) were calculated during the entire squat movement using a trapezoidal function.

From the force plate, peak vertical GRF (N/kg) during the ascent phase of the lift was extracted. The RFD of the vertical GRF (N/kg/s) was also calculated by obtaining the peak increase in vertical GRF force between adjacent data points again using the first derivative function within Visual 3D. In addition, the integral of the vertical, medio-lateral anterio-posterior GRF's (N/kg·s) were calculated during both the ascent and descent phases of the lift, again using a trapezoidal function. Furthermore, the peak power applied to the centre of mass (W/kg) during ascent phase was extracted using a product of the vertical GRF and the vertical velocity of the model centre of mass within Visual 3D. The total lift duration was also calculated using the time difference from the initiation to the end of each repetition, and the absolute duration of the ascent/ descent phases (s) was also extracted as was the % duration of the ascent/ descent phases, which were expressed as a function of the total lift duration.

Statistical analyses

Descriptive statistics of means and standard deviations were obtained for each outcome measure. Shapiro-Wilk tests were used to screen the data for normality. Differences in biomechanical parameters between each of the four conditions were examined using one-way repeated measures ANOVA's. Effect sizes were calculated using partial eta^2 ($p\eta^2$). Effect sizes were characterized as small = 0.01, medium = 0.06 and large = 0.14. In the event of a significant main effect, post-hoc pairwise comparisons were conducted. In addition, the data from participants' subjective ratings in relation to their preferred condition and also in regards to the stability and comfort of each sleeve/ wrap were explored using Chi-Square (X^2) tests. Statistical actions were conducted using SPSS v25.0 (SPSS Inc., Chicago, USA) and Statistical significance was accepted at the $P \leq 0.05$ level.

Results

Kinetic and temporal parameters

There was a significant main effect for the integral of the vertical GRF during the descent phase ($P \leq 0.05$, $p\eta^2 = 0.19$). Post-hoc pairwise comparisons showed that the vertical GRF integral was significantly greater in the knee sleeve compared to the nothing condition (P=0.01) and in the competition wrap in relation to the knee sleeve (P=0.036). There was also a main effect for the extent of anterior bar displacement ($P \leq 0.05$, $p\eta^2 = 0.25$). Post-hoc pairwise comparisons showed that bar displacement was significantly greater in the nothing condition compared to the competition ($P=0.004$) and training ($P=0.024$) wraps.

In addition, there was a significant main effect for the duration of the ascent phase ($P \leq 0.05$, $p\eta^2 = 0.35$). Post-hoc pairwise comparisons showed that this duration was significantly greater in the nothing condition compared to the sleeve ($P=0.003$), competition wrap ($P<0.001$) and training wrap ($P=0.005$). There was a significant main effect for the percentage duration of the ascent phase ($P \leq 0.05$, $p\eta^2 = 0.35$). Post-hoc pairwise comparisons showed that this duration was significantly greater in the nothing condition compared to the sleeve ($P=0.01$), competition wrap ($P=0.002$) and training wrap ($P=0.01$). In addition, it was also shown that percentage ascent phase duration was significantly greater in the knee sleeve compared to the competition wrap. A significant main effect for the percentage duration of the descent phase was also found ($P \leq 0.05$, $p\eta^2 = 0.35$). Post-hoc pairwise comparisons showed that this duration was significantly greater in the sleeve ($P=0.01$), competition wrap ($P=0.002$) and training wrap ($P=0.01$) compared to the nothing condition. In addition it was also shown that percentage descent phase duration was significantly greater in the competition wrap compared to the knee sleeve ($P=0.009$).

There was also a main effect for the extent of anterior knee translation ($P \leq 0.05$, $p\eta^2 = 0.16$). Post-hoc pairwise comparisons showed that knee translation was significantly greater in the nothing condition ($P=0.02$) compared to the competition wrap. Finally, there was a main effect for the extent of lateral knee displacement ($P \leq 0.05$, $p\eta^2 = 0.32$). Post-hoc pairwise comparisons showed that lateral displacement was significantly greater in the nothing

(P=0.03 & P=0.04) and sleeve (P=0.008 & P=0.002) conditions compared to the competition and training wraps.

@@@TABLE 1 NEAR HERE@@@

Muscle forces

There was a significant main effect for the integral of the quadriceps force during the ascent phase ($P \leq 0.05$, $p\eta^2 = 0.16$). Post-hoc pairwise comparisons showed that the integral was significantly larger in the nothing condition (P=0.035) compared to the competition wrap. In addition, there was a significant main effect for the integral of the gluteus maximus force during the ascent phase ($P \leq 0.05$, $p\eta^2 = 0.18$). Post-hoc pairwise comparisons showed that the gluteus maximus integral was significantly larger in the nothing condition (P=0.007) compared to the training wrap. There was also significant main effect for the integral of the hamstring force during the ascent phase ($P \leq 0.05$, $p\eta^2 = 0.18$). Post-hoc pairwise comparisons showed that the hamstring integral was significantly larger in the nothing condition (P=0.018) compared to the training wrap. There was a significant main effect for the integral of the gastrocnemius force during the ascent phase ($P \leq 0.05$, $p\eta^2 = 0.26$). Post-hoc pairwise comparisons showed that the gastrocnemius integral was significantly larger in the nothing (P=0.016) and sleeve (P=0.012) conditions compared to the competition wrap. Finally, there was a significant main effect for the integral of the soleus force during the ascent phase ($P \leq 0.05$, $p\eta^2 = 0.25$). Post-hoc pairwise comparisons showed that the soleus integral was significantly larger in the nothing (P=0.015) and sleeve (P=0.012) conditions compared to the competition wrap.

@@@TABLE 2 NEAR HERE@@@

Knee forces

There was a significant main effect for the peak knee shear force ($P \leq 0.05$, $p\eta^2 = 0.25$). Post-hoc pairwise comparisons showed that the peak shear force was significantly greater in the nothing (P=0.009) and knee sleeve (P=0.019) compared to the competition wrap condition.

@@@TABLE 3 NEAR HERE@@@

Kinematics

There was a significant main effect for peak hip internal rotation ($P \leq 0.05$, $p\eta^2 = 0.39$). Post-hoc pairwise comparisons showed that peak internal rotation was significantly larger in the competition and training wraps compared to the nothing (P=0.001 & P=0.001) and knee sleeve conditions (p=0.019 & p=0.002).

There was a significant main effect for the sagittal plane knee ROM ($P \leq 0.05$, $p\eta^2 = 0.20$). Post-hoc pairwise comparisons showed that ROM was significantly larger in the knee nothing condition compared to competition wrap (P=0.04) and in the knee sleeve in relation to the competition (P=0.03) and training wraps (P=0.004). There was also a significant main effect for the peak knee adduction angle ($P \leq 0.05$, $p\eta^2 = 0.40$). Post-hoc pairwise comparisons showed that peak knee adduction was significantly larger in the competition and training wraps compared to the nothing (P<0.001 & P=0.008) and knee sleeve conditions (p<0.001 & p=0.005). There was also a main effect for the knee coronal plane ROM ($P \leq 0.05$, $p\eta^2 = 0.37$). Post-hoc pairwise comparisons showed that knee coronal plane ROM was significantly larger in the competition and training wraps compared to the nothing (P<0.001 & P=0.001) and knee sleeve conditions (p=0.013 & p=0.012).

There was a significant main effect for peak knee internal rotation ($P \leq 0.05$, $p\eta^2 = 0.31$). Post-hoc pairwise comparisons showed that peak internal rotation was significantly larger in the competition (P=0.001) and training (P<0001) wraps compared to the nothing condition. There was also a main effect for the knee transverse plane ROM ($P \leq 0.05$, $p\eta^2 = 0.28$). Post-hoc pairwise comparisons showed that knee transverse plane ROM was significantly larger in the competition (P=0.001) and training (P=0.001) wraps compared to the nothing condition, and in the training wrap (P=0.04) compared to the sleeve condition.

There was a significant main effect for peak ankle dorsiflexion ($P \leq 0.05$, $p\eta^2 = 0.23$). Post-hoc pairwise comparisons showed that peak dorsiflexion was significantly larger in the nothing (P=0.001) and sleeve (P=0.005) conditions compared to the competition wrap. There was also a significant main effect for the sagittal plane ankle ROM ($P \leq 0.05$, $p\eta^2 = 0.45$). Post-hoc pairwise comparisons showed that sagittal plane ankle ROM was significantly larger in the nothing condition compared to the competition (P<0.001) and training wrap (P=0.03) and in the sleeve condition in relation to the competition wrap (P<0.001).

There was a significant main effect for peak ankle eversion ($P \leq 0.05$, $p\eta^2 = 0.28$). Post-hoc pairwise comparisons showed that peak eversion was significantly larger in the sleeve (P=0.04), training wrap (P=0.002) and competition wrap (P=0.02) compared to the nothing condition. There was also a significant main effect for the coronal plane ankle ROM ($P \leq 0.05$, $p\eta^2 = 0.21$). Post-hoc pairwise comparisons showed that coronal plane ankle ROM was significantly larger in the nothing condition compared to the competition (P=0.007) and training wrap (P=0.01).

@@@TABLE 4 NEAR HERE@@@

Subjective ratings

For the subjectively preferred condition 7 participants selected the sleeve, 3 the nothing condition, 3 the training wrap and 2 the competition wrap. The chi-squared test was significant ($X^2 = 3.93$, $P<0.05$) and indicated that there was a preference towards the sleeve condition. For the subjective ratings of comfort in the sleeve, 9 participants rated that this condition improved comfort, 4 no-change and 2 reduced comfort. The chi-squared test was significant ($X^2 = 5.20$, $P<0.05$) and significantly more participants found that the sleeve provided improved comfort. For the ratings of knee stability in the sleeve, 10 participants rated that this condition improved stability, 3 no-change and 2 reduced stability. The chi-squared test was significant ($X^2 = 7.60$, $P<0.05$) and significantly more participants found that the sleeve provided improved stability. For the subjective ratings of comfort in the training wrap, 2 participants rated that this condition improved comfort, 3 no-change and 10 reduced comfort. The chi-squared test was significant ($X^2 = 7.60$, $P<0.05$) and showed that significantly more participants found that the training wrap reduced comfort. For the ratings of knee stability in the training wrap, 9 participants rated that this condition improved stability, 4 no-change and 2 reduced stability. The chi-squared test was significant (X^2= 5.20, P<0.05) and significantly more participants found that the training wrap provided improved stability. For the subjective ratings of comfort in the competition wrap, 2 participants rated that this condition improved comfort, 4 no-change and 9 reduced comfort. The chi-squared test was significant (X^2 = 5.20, P<0.05) and showed that significantly more participants found that the competition wrap reduced comfort. For the ratings of knee stability in the competition wrap, 11 participants rated that this condition improved stability, 2 no-change and 2 reduced stability. The chi-squared test was significant (X^2= 10.80, P<0.05) and significantly more participants found that the competition wrap provided improved stability.

Discussion

The aim of the current investigation was to comparatively examine the effects of knee wraps/ sleeves on kinetics, three-dimensional kinematics and muscle forces during the squat. To the authors knowledge this investigation represents the first to explore the aforementioned aims and may provide further insight regarding the effects of knee wraps/ sleeves on the mechanics of the barbell back squat.

Previous analyses have shown that knee wraps influence performance parameters during the back squat. Specifically, Lake et al., (3) showed that knee wraps significantly enhanced mechanical power output during the ascent phase of the lift. The findings from the current investigation do not support these observations as no significant alterations in power output or GRF parameters during the ascent phase were evident as a function of wearing knee wraps/ sleeves. Similarly, Lake et al., (3) showed that the lowering phase was performed faster when knee wraps were worn, allowing elastic potential energy to be stored within the knee wraps, increasing the vertical force applied to the centre of mass and augmenting the power output during the ascent phase. The findings from this investigation do not agree with those of Lake et al, (3), as the knee sleeve/ wraps increased the descent phase and decreased the ascent phase duration, which may serve as the mechanical explanation for the lack of improvements in performance parameters. The lack of agreement between analyses may be due to the lower relative and absolute mass being lifted, alongside the participants' lack of familiarity in using knee wraps/ sleeves. In contrast to the current study, in the investigation of Lake et al., (3), athletes lifted at 80% of 1RM relative to a group maximum squat capacity of 160.5 kg and had previous experience of squatting using knee wraps. The findings from the current investigation therefore indicate that knee wraps/ sleeves may not mediate improvements in performance parameters when lower masses are being lifted, in athletes who are not accustomed to using them. This leads to the notion that the mechanical effects of knee wraps/ sleeves may be mass (lifted) and experience dependant, and this is something that future research should seek to full substantiate.

Importantly, the current investigation did show that muscle force parameters were significantly influenced by the experimental conditions. Specifically, knee wraps statistically reduced the integral of each muscle group during the ascent phase compared to the nothing condition, and in the gastrocnemius and soleus muscles in relation to the knee sleeve. This observation supports the findings of Gomes et al., (6) who showed using EMG that knee wraps statistically influenced muscle outputs during the ascent phase, and also the proposition suggested by Lake et al., (3) that knee wraps may affect the target musculature.

Gomes et al., (6) hypothesized that reductions in vastus lateralis muscle recruitment were initiated by tissue pressure imposed by the knee wrap, leading to inhibition of the muscle motoneuron pool. However, the current investigation indicates that this may not be the case, as reductions were found in musculature that does not directly interface with the knee wraps. It is proposed that the aforementioned reductions in muscle kinetics were mediated by carryover (5). Muscle force attenuation in the knee wrap/ sleeve conditions was due (in spite of the same absolute load being lifted) to the lifters operating at a lower relative intensity compared to squatting without external aid. This indicates that lifters who utilize knee wraps/ sleeves may be able to lift greater maximal loads during competition or perform additional repetitions with a given load. Nonetheless, mechanical tension is the primary driver of muscle hypertrophy (1) and the cross-sectional area is the key determiner of muscle force production (25). As such, skeletal muscle training impulses determine the magnitude of adaptive hypertrophic and performance responses (26). Therefore, as knee wraps significantly reduced lower extremity muscular recruitment during the ascent phase, this indicates that their utilization in relation to the nothing and (to a lesser extent) knee sleeve conditions may not be advisable in athletes seeking to maximise training adaptations.

In agreement with the findings of Lake et al., (3) this study showed that knee wraps significantly altered movement patterns during the back squat exercise, in relation to squatting in the nothing condition. Importantly, sagittal plane knee ROM and the anterior knee translation were statistically reduced in the knee wraps compared to the nothing condition. It is likely that the reduced knee translation/ flexion ROM were responsible for the reductions in horizontal bar displacement that were similarly shown in the knee wrap conditions. Similar to Lake et al., (3) this observation is supported by the anterior-posterior GRF integral during the descent phase, which was to be posteriorly orientated in both knee wraps but directed anteriorly in the nothing condition and knee sleeve. The above observations are supported by the subjective ratings of the knee wrap conditions, which indicate that knee stability was significantly enhanced but with corresponding reductions in perceived comfort. The above observations reinforce the propositions of both Lake et al., (3) and Gomes et al., (6) who postulated that the discomfort mediated by knee wraps creates a physical barrier about the knee joint. From and injury prevention perspective it could nonetheless be interpreted that the decreases in anterior knee translation were important given the attenuation of the peak knee shear force when wearing knee wraps. However, taking into account knee wraps potential to diminish lower extremity muscle development and alter natural squatting mechanics; further analyses are required before this could be properly established.

In addition to the above, it was also revealed that both coronal and transverse plane hip and knee kinematics were significantly influenced by the competition and training knee wrap conditions. This observation was likely mediated by the reductions in lateral knee displacement that were observed when wearing knee wraps and reinforces the Lake et al., (3) and Gomes et al., (6) notion in relation to the physical restriction about the knee joint. In conjunction with the results outlined previously, this finding provides further evidence to show that knee wraps influence natural squatting mechanics as differences in relation to the nothing condition were observed all three planes of rotation.

Finally, like the knee wrap conditions the knee sleeve did not mediate improvements in mechanical power output and statistically influenced the duration of the different phases of the squat. However, unlike the knee wraps the knee sleeves did not significantly alter natural squatting mechanics or influence muscle kinetics during the ascent phase in relation to the nothing condition. It is proposed that this observation was mediated by the significant improvements in both perceived comfort and stability that were noted in the knee sleeves in relation to the nothing condition. Therefore, taking the above into account and the subjective preference towards this condition, the findings from the current investigation indicate that knee sleeves may be more efficacious for athletes who regularly utilize the back squat for their training goals, although future longitudinal studies are required before this can be fully substantiated.

A potential drawback to the current investigation is that only recreational lifters were examined as part of the current study. Previous analyses have shown that squat experience can significantly influence the biomechanics of performing the squat itself (27). Therefore, it is not currently known whether more experienced lifters would exhibit the same biomechanical responses to the experimental knee wrap/ sleeve conditions examined in the current investigation. Therefore, it is recommended that the current analysis be repeated using a more experienced group of lifters.

In conclusion, the effects of knee wraps/ sleeves on the biomechanics of the barbell back squat have received limited research attention. Therefore, the present study adds to the current scientific knowledge, by providing a comprehensive evaluation regarding the effects of knee wraps/ sleeves on kinetics, three-dimensional kinematics and muscle forces during the squat. Importantly, knee wraps significantly reduced lower extremity muscle integrals during the ascent phase, natural squatting mechanics in all three planes of rotation and also reduced perceived comfort. However, knee sleeves were conversely able to mediate significant improvements in both perceived comfort and stability but did not significantly alter natural squatting mechanics or influence muscle kinetics during the ascent phase. Taking into account the potential of knee wraps to diminish lower extremity muscle development; knee sleeves may be more efficacious for athletes who regularly utilize the back squat for their training goals, although further longitudinal analyses are required before this can be fully established.

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Table 1: Kinetic and temporal parameters (Mean ± SD) as a function of each experimental condition.

	Nothing		Sleeve		Competition wrap		Training wrap		
	Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*	
Peak bar velocity (m/s)	1.01	0.14	1.11	0.37	1.05	0.17	1.05	0.18	
Anterior bar displacement (m)	0.09	0.03	0.08	0.03	0.07	0.02	0.08	0.02	
Total duration (s)	2.60	0.36	2.56	0.39	2.59	0.42	2.53	0.45	
Ascent duration (s)	1.33 ***ABC***	0.20	1.27	0.21	1.21	0.17	1.22	0.19	*
Descent duration (s)	1.27	0.26	1.29	0.29	1.38	0.32	1.31	0.32	
Ascent percent duration (%)	51.35 ***ABC***	5.20	49.91	5.64	47.56	5.73	48.72	5.14	*
Descent percent duration (%)	48.65 ***ABC***	5.20	50.09	5.64	52.44	5.73	51.28	5.14	*
Knee anterior translation (cm)	20.50 ***B***	2.87	20.49	3.56	19.07	4.06	19.93	4.45	*
Knee lateral translation (cm)	13.41 ***BC***	3.04	13.85 ***BC***	3.53	12.29	2.88	12.51	3.06	*
Peak vertical force (N/kg)	12.80	2.06	13.19	1.77	12.83	1.45	13.19	1.69	
RFD (N/kg/s)	68.51	23.85	64.79	20.01	65.89	24.98	63.67	21.11	
Medial GRF integral ascent (N/kg·s)	1.80	0.81	1.74	0.76	1.84	0.81	1.68	0.74	
Posterior GRF integral ascent (N/kg·s)	0.04	0.12	0.04	0.13	0.02	0.13	0.02	0.16	
Vertical GRF integral ascent (N/kg·s)	13.09	3.28	12.83	2.61	12.33	2.60	12.38	2.91	
Medial GRF integral descent (N/kg·s)	1.43	0.68	1.50	0.71	1.88	0.89	1.60	0.80	
Posterior GRF integral descent (N/kg·s)	-0.02	0.08	-0.02	0.09	0.02	0.11	0.01	0.13	
Vertical GRF integral descent (N/kg·s)	12.61 ***A***	2.91	13.00	2.70	14.17 ***A***	3.69	13.47	3.77	*
Peak knee shear force (N/kg)	7.68	2.15	7.62	2.09	6.90	1.82	7.57	2.21	
Peak power (W/kg)	20.21	4.58	19.55	3.94	19.73	2.95	20.84	4.05	
Stance width (m)	0.49	0.06	0.49	0.06	0.50	0.06	0.49	0.05	

Key: * = significant main effect
A = significantly different from Sleeve
B = significantly different from Competition wrap
C = significantly different from Training wrap

Table 2: Muscle forces (Mean ± SD) as a function of each experimental condition.

	Nothing		Sleeve		Competition wrap		Training wrap		
	Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*	
Peak quadriceps force (N/kg)	81.22	16.66	79.97	18.75	77.96	15.25	83.51	22.19	
Quadriceps integral ascent (N/kg·s)	58.30 ***B***	20.09	54.67	16.01	51.87	19.02	53.33	22.03	*
Quadriceps integral descent (N/kg·s)	63.58	22.86	61.54	19.84	63.39	24.63	62.97	27.15	
Quadriceps RFD (N/kg/s)	78.05	36.73	74.63	34.82	94.09	76.30	100.22	67.03	
Peak Gluteus Maximus force (N/kg)	41.75	19.41	39.32	13.34	43.47	23.01	40.76	20.84	
Gluteus Maximus integral ascent (N/kg·s)	24.29 ***C***	9.62	21.78	5.85	22.22	8.91	21.03	7.23	*
Gluteus Maximus integral descent (N/kg·s)	21.42	8.38	20.84	6.43	23.84	9.66	20.25	6.50	
Gluteus Maximus RFD (N/kg/s)	38.11	21.88	30.83	17.16	46.53	41.75	36.29	22.28	
Peak Hamstring force (N/kg)	64.89	25.86	63.74	18.54	66.51	28.27	62.50	24.55	
Hamstring integral ascent (N/kg·s)	39.01 ***C***	15.34	35.74	9.58	35.61	14.02	33.97	11.58	*
Hamstring integral descent (N/kg·s)	34.51	13.68	34.25	10.87	38.44	15.51	32.64	10.38	
Hamstring RFD (N/kg/s)	53.20	29.17	46.12	27.96	59.17	49.15	52.63	33.06	
Peak Gastrocnemius force (N/kg)	8.14	1.79	7.84	1.78	7.70	1.35	7.87	1.20	
Gastrocnemius integral ascent (N/kg·s)	7.25 ***B***	3.09	6.85 ***B***	2.76	5.97	2.54	6.39	2.16	*
Gastrocnemius integral descent (N/kg·s)	5.55	2.21	5.92	2.42	6.12	2.56	5.70	1.79	
Gastrocnemius RFD (N/kg/s)	27.94	11.09	21.87	5.51	26.33	7.51	31.75	21.76	
Peak Soleus force (N/kg)	17.38	3.82	16.74	3.80	16.44	2.88	16.81	2.56	
Soleus integral ascent (N/kg·s)	15.49 ***B***	6.61	14.62 ***B***	5.90	12.75	5.42	13.64	4.61	*
Soleus integral descent (N/kg·s)	11.85	4.71	12.63	5.16	13.06	5.46	12.16	3.82	
Soleus RFD (N/kg/s)	59.66	23.67	46.70	11.75	56.21	16.04	67.78	46.45	

Key: * = significant main effect
A = significantly different from Sleeve
B = significantly different from Competition wrap
C = significantly different from Training wrap

Table 3: Knee forces (Mean ± SD) as a function of each experimental condition.

	Nothing		Sleeve		Competition wrap		Training wrap		
	Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*	
Peak knee shear force (N/kg)	7.68 ***B***	2.15	7.62 ***B***	2.09	6.90	1.82	7.25	2.20	*
Knee shear force integral (N/kg·s)	12.31	5.15	12.01	4.67	11.34	4.93	11.77	5.51	
Knee shear force instantaneous load rate (N/kg/s)	30.03	10.63	29.68	7.80	26.80	7.83	28.73	9.91	
Peak patellar tendon force (N/kg)	62.08	21.50	63.34	22.50	57.91	20.03	64.70	25.89	
Patellar tendon force integral (N/kg·s)	85.47	35.29	81.28	28.93	79.45	35.62	84.09	44.75	
Patellar tendon force instantaneous load rate (N/kg/s)	264.35	99.95	261.90	77.17	240.70	84.61	258.67	94.49	
Peak patellofemoral force (N/kg)	46.78	10.68	46.81	12.02	45.54	9.67	49.22	14.14	
Patellofemoral force integral (N/kg·s)	67.93	24.03	65.27	18.69	64.44	25.01	66.19	29.46	
Patellofemoral force instantaneous load rate (N/kg/s)	196.02	68.09	177.75	46.28	167.43	54.13	187.48	71.96	
Patellofemoral tendon stress (KPa/kg)	58.50	13.35	57.76	13.63	56.52	12.12	60.51	17.30	
Patellofemoral stress integral (KPa/kg·s)	88.90	31.29	85.31	23.93	84.63	32.23	87.31	38.94	
Patellofemoral stress instantaneous load rate (KPa/kg/s)	298.41	108.48	284.00	82.99	272.84	106.87	291.39	99.66	

Key: * = significant main effect
A = significantly different from Sleeve
B = significantly different from Competition wrap
C = significantly different from Training wrap

Table 4: Kinematic parameters (Mean ± SD) as a function of each experimental condition.

	Nothing		Sleeve		Competition wrap		Training wrap		
Trunk (Sagittal plane)	**Mean**	***SD***	**Mean**	***SD***	**Mean**	***SD***	**Mean**	***SD***	
Peak flexion (°)	38.58	6.72	37.82	6.85	38.01	6.14	37.85	6.01	
ROM (°)	28.19	3.90	27.62	4.78	27.29	4.38	27.55	4.54	
Hip (Sagittal plane + = flexion)									
Peak flexion (°)	106.70	19.15	107.14	18.15	106.50	16.76	103.81	19.32	
ROM (°)	87.38	18.15	92.39	14.48	86.19	14.82	89.73	15.62	
Hip (Coronal plane + = adduction)									
Peak abduction (°)	-29.07	8.25	-30.80	7.76	-29.56	5.72	-30.08	7.89	
ROM (°)	18.52	8.46	20.79	7.60	18.72	6.21	18.94	8.26	
Hip (Transverse plane + = internal rotation)									
Peak internal rotation (°)	10.80 ***BC***	13.19	11.50 ***BC***	13.44	18.78	11.21	21.19	9.29	*
ROM (°)	26.48	10.33	27.67	9.64	24.72	8.26	29.63	10.97	
Knee (Sagittal plane + = flexion)									
Peak flexion (°)	117.76	15.88	117.27	14.94	114.06	14.47	115.58	15.80	
ROM (°)	109.57	14.25	111.14	13.29	105.96	14.39	107.41	15.30	*
Knee (Coronal plane + = adduction)									
Peak adduction (°)	8.64 ***BC***	5.38	9.27 ***BC***	6.86	17.65	6.76	17.44	6.55	*
ROM (°)	6.87 ***BC***	4.25	7.41 ***BC***	5.64	14.81	7.25	15.03	6.51	*
Knee (Transverse plane + = internal rotation)									
Peak internal rotation (°)	19.81 ***BC***	9.32	24.26	15.79	31.45	12.70	29.62	10.59	*
ROM (°)	22.95 ***BC***	11.61	24.86 ***C***	18.82	34.17	12.41	33.12	10.59	*
Ankle (Sagittal plane + = dorsiflexion)									
Peak dorsiflexion (°)	27.72 ***B***	5.65	27.46 ***B***	6.04	23.96	5.98	25.91	7.29	*
ROM (°)	28.29 ***BC***	5.64	27.89 ***B***	5.76	24.04	6.55	26.28	6.68	*
Ankle (Coronal plane + = inversion)									
Peak eversion (°)	-9.14 ***ABC***	5.13	-11.43	6.90	-14.31	7.13	-12.23	4.84	*
ROM (°)	9.25 ***BC***	4.28	11.08	5.61	12.72	4.81	12.38	3.53	*
Ankle (Transverse plane + = internal rotation)									
Peak external rotation (°)	-6.36	5.10	-4.74	4.00	-4.95	5.31	-3.52	5.62	
ROM (°)	8.34	4.42	7.14	4.56	8.02	5.09	6.89	4.14	

Key: * = significant main effect
A = significantly different from Sleeve
B = significantly different from Competition wrap
C = significantly different from Training wrap