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Kinematic and sEMG Analysis of the Back Squat at Different Intensities With and Without Knee Wraps

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Abstract

Gomes, WA, Brown, LE, Soares, EG, da Silva, JJ, Silva, FHDdO, Serpa, ÉP, Corrêa, DA, Vilela Junior, GdB, Lopes, CR, and Marchetti, PH. Kinematic and sEMG analysis of the back squat at different intensities with and without knee wraps. *J Strength Cond Res* 29(9): 2482–2487, 2015—The purposes of this study were to measure the acute effects of knee wraps (KWs) on knee and hip joint kinematics, dynamic muscle activation from the vastus lateralis (VL) and gluteus maximus (GM), and rating of perceived exertion (RPE) during the back squat exercise at 2 different intensities. Fourteen resistance-trained men (age: 24 ± 4 years, height: 176 ± 6 cm, body mass: 81 ± 11 kg, back squat 1 repetition maximum [1RM]: 107 ± 30 kg, 3 ± 1 year of back squat experience) performed 1 set of 3 repetitions under 4 different conditions, to a depth of approximately 90 degrees of knee joint flexion, and in random order: KWs at 60% 1RM (KW60), KWs at 90% 1RM (KW90), without knee wraps (NWs) at 60% 1RM (NW60), and NWs at 90% 1RM (NW90). The dependent variables obtained were vertical and horizontal bar displacement, peak joint angle in the sagittal plane (hip and knee joints), concentric and eccentric muscle activation (by integrated electromyography) from the VL and GM, and RPE. For muscle activity, there were significant decreases in the VL NWs at 60% 1RM ($p = 0.013$) and a significant increase NWs at 90% 1RM ($p = 0.037$). There was a significant increase in VL muscle activity at 90% 1RM, when compared with 60% 1RM (KW: $p = 0.001$, effect size (ES) = 1.51 and NW: $p < 00.001$, ES = 1.67). There was a decrease in GM muscle activity NWs only at 60% 1RM ($p = 0.014$). There was a significant increase in GM muscle activity at 90% 1RM, when compared with 60% 1RM (KW: $p < 0.001$ and NW: $p < 0.001$). For peak hip joint flexion angle, there was significant decreases between intensities (90% 1RM < 60% 1RM) only to NWs condition ($p = 0.009$), and there was greater knee flexion NWs for both intensities: 60% 1RM ($p < 0.001$) and 90% 1RM ($p = 0.018$). For normalized vertical barbell displacement, there were significant differences between intensities when using KWs ($p = 0.022$). There were significant differences in RPE between 60 and 90% 1RM for each condition: KWs ($p < 0.001$) and NWs ($p < 0.001$). In conclusion, the use of KWs results in decreased muscle activation of the VL at the same intensity (90% 1RM).

Key Words barbell displacement, force, power

Introduction

Knee wraps (KWs) are typically worn to gain mechanical advantage during the back squat exercise, and they are also often used to increase the load lifted or the number of repetitions performed with a given load (4,9,10,13,18). In general, when the knee is flexed against an external resistance during the back squat exercise, the KW(s) elastic material is stretched during the eccentric phase and returns this energy during the concentric phase. This potential accumulated energy is transferred to the lifter and added to the strength of the movement. This additional force (~22%) is known as carryover (9,18).

Some previous studies have demonstrated the effects of KWs on the back squat exercise. Eiter et al. (4) analyzed powerlifters using 1 set of 6 repetitions at a 12 repetition maximum (RM) load. They analyzed execution time, percentage of the transition cycle of the center of mass during the concentric and eccentric phase, and bar vertical displacement, with and without knee wraps (NWs). Their results showed no differences in biomechanics, and no effect of KWs on work performed in the hips or knees. However, Lake et al. (13) examined trained subjects, with and without

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knee wraps, by performing 6 single back squats with 80% 1RM. They observed that the elastic properties of the KWs increased mechanical output by altering the back squat technique in a way that is likely to alter the target musculature. Their results suggest that wearing KWs restricts motion around the hip joint, which causes a more upright posture and greater flexion at the knee joint.

Therefore, wearing KWs may affect traditional movement patterns by increasing mechanical output during the back squat exercise and consequently change exercise technique (13). Additionally, because the back squat exercise is a multijoint exercise, any effect on the extensor knee torque may alter the level of internal torque in both the knee and hip joints. Consequently, this may result in a different bar displacement pattern. We are unaware of any previous work evaluating by rating of perceived exertion (RPE) with or without knee wraps. Therefore, the purposes of this study were to measure the acute effects of KWs during the back squat exercise at 2 different intensities on knee and hip joint kinematics, muscle activation, and RPE.

Methods

Experimental Approach to the Problem

An experimental design was used to test the hypothesis that wearing KWs during the back squat exercise would acutely affect the knee and hip joint kinematics, surface electromyography (sEMG), and RPE at 2 different intensities. Resistance-trained men with experience wearing KWs while back squatting took part in the study and performed 1 set of 3 repetitions under 4 different random conditions: KWs at 60% 1RM (KW60) and 90% 1RM (KW90), without knee wraps at 60% 1RM (NW60), and 90% 1RM (NW90). Differences between conditions were quantified by the dependent variables of vertical and horizontal bar displacement, peak angle of the hip and knee joints in the sagittal plane, muscle activation of the vastus lateralis (VL) and gluteus maximus (GM), and RPE.

Subjects

Based on a statistical power analysis derived from the 1RM data from a pilot study, 10 subjects were necessary to achieve an alpha level of 0.05 and a power ($1 - \beta$) of 0.80 (5). Therefore, we recruited 14 young, healthy resistance-trained men (age: 24 ± 4 years, height: 176 ± 6 cm, body mass: 81 ± 11 kg, back squat 1RM: 107 ± 30 kg) to participate in this study. They had 3 ± 1 years of experience with the back squat exercise and had all squatted KWs, although not regularly. Their training was similar during the last year (hypertrophy), for all subjects, considering that they participated in the same program at the University. Participants had no previous surgery on their lower extremities and no history of lower limb injury with residual symptoms within the last year. This study was approved by the University research ethics committee, and all subjects read and signed an informed consent document before participating.

Procedures

Before data collection, subjects were asked to identify their preferred leg for kicking a ball, which was then considered their dominant leg (15). All subjects were right-leg dominant. They attended 2 sessions in the laboratory, separated by 1 week. During the first session, maximal back squat strength (1RM), NWs, was established using a protocol described by Brown and Weir (2). Knee wraps were not used during the 1RM test because the main objective was to define the maximum lift without aid. Because none of the subjects used KWs regularly, they performed a familiarization session with and without knee wraps approximately 15 minutes after 1RM testing that included 4 sets of 10 repetitions at 50% of their 1RM. In the second session, subjects warmed up by performing (1) 1 set of 8–10 repetitions at 30% 1RM followed by 3-minute rest, and (2) a second set of 2–3 repetitions at 80% 1RM NWs. Then, after 10 minutes, all subjects performed 1 set of 3 repetitions (at a self-selected cadence) under 4 different conditions in random order: KWs at 60% 1RM (KW60) and 90% 1RM (KW90), NWs at 60% 1RM (NW60), and 90% 1RM (NW90). A rest period of 10 minutes was used between conditions. A step was positioned behind each subject ensuring that the descent phase continued until the tops of the thighs were parallel to the ground (~90 degrees of knee joint flexion). Subjects were instructed to perform the ascent phase as quickly as possible. Knee wraps (Maba Murphy Confecções Ltda., Blumenau, SC, Brazil) were 0.02 × 0.08 × 2.00 m and were composed of a heavy cotton fabric with interwoven elastic rubber filaments, similar to those used in previous studies (9). All KWs were new and not previously used. The "spiral figure" wrapping technique was used on both legs (3,8,14). The same researcher applied the wraps as tightly as possible immediately before each trial, standardizing the number of wrap revolutions to 9 per subject. All measures were performed at the same hour of the day, between 9 AM and 12 PM.

Measures

Surface Electromyography. The participants' skin was prepared by shaving hair at the site of the electrode placement and cleaned with alcohol. Bipolar passive disposable dual Ag/AgCl snap electrodes were used that were 1 cm in diameter with 2-cm center-to-center spacing. These were placed on the dominant limb over the longitudinal axes of the GM at 50% of the distance between the sacral vertebrae and the greater trochanter and on the VL at 2/3 of the distance between the anterior spina iliaca and the superior aspect of the lateral side of the patella, according to the SENIAM/ISEKI protocol (11). These muscles were chosen for their single-joint effect during the back squat exercise. The sEMG signals of the GM and VL were recorded by an electromyographic acquisition system (EMG832C; EMG system Brasil, São José dos Campos, Brasil) with a sampling rate of 2,000 Hz using a commercially designed software program (DATAQ Instruments Hardware Manager; DATAQ Instruments, Inc., Akron, Ohio). Electromyographic activity was amplified (bipolar differential amplifier, input impedance = 2 MΩ, common mode rejection ratio > 100 dB min^{-1}

(60 Hz), gain × 20, noise >5 μV) and analog-to-digitally converted (12 bit). A ground electrode was placed on the right clavicle. Surface electromyography signals collected during all conditions were normalized to a maximum voluntary isometric contraction (MVIC) against a fixed resistance. Then, 2 trials of 5-second MVICs were performed for each muscle with the dominant leg only, with 1-minute rest between actions. For GM MVIC, subjects were in the prone position with their knee flexed at 90° with resistance placed on the distal region of their thigh with their pelvis in a stabilized position. They then performed a hip extension MVIC against a fixed resistance. For VL MVIC, they were in a sitting position with their knee flexed at 90° and resistance placed on the distal tibia. Then, they performed a knee extension MVIC against a fixed resistance. Verbal encouragement was given during all MVICs, and the order was counterbalanced to avoid any potential bias.

Kinematic and Kinetic Analyses. Bidimensional kinematic analyses of the lower limb and barbell trajectory were performed using a single camera system (Sony CX505VE 32 GB HDD model; New York, NY, USA), sampling at 30 Hz. Eight spherical markers were attached to the skin with double-faced adhesive tape at the following locations: over the acromion, seventh rib, anterosuperior iliac spine, greater trochanter, lateral femoral condyle, lateral tibia condyle, lateral malleolus, and the fifth metatarsal. A marker was also affixed to the end of the barbell. The camera was positioned 8 m from and perpendicular to the dominant side of the subject (sagittal plane). Kinetic data were collected with a force plate (Biomec410; EMG System do Brasil, São José dos Campos, Brazil) sampling at 2,000 Hz. Vertical ground reaction force (vGRF) was only recorded from the dominant lower limb using a commercial software program (DATAQ Instruments Hardware Manager; DATAQ Instruments, Inc.).

Rating of Perceived Exertion. For assessing RPE (CR-10 scale) during the exercise sessions, anchoring procedures were explained during the familiarization session. Subjects were asked to use any number on the scale to rate their overall effort for each condition. A rating of 0 was associated with no effort and a rating of 10 was associated with maximal effort, and the most stressful exercise ever performed. Subjects were shown the scale 3 minutes after each condition and asked: “How was your workout?” (1).

Statistical Analyses

All force plate and sEMG data were analyzed with a customized Matlab routine (MathWorks, Inc., Natick, MA, USA) and defined by the vGRF data, characterizing both the concentric and eccentric phases of each repetition.

The digitized sEMG data were band-pass filtered at 20–400 Hz using a fourth-order Butterworth filter with a zero lag. For muscle activation (concentric and eccentric phase) time-domain analysis, a root mean square (RMS) (150-millisecond moving window) was calculated during the MVIC. Back squat data were then normalized to both the temporal base and the RMS average of the 2 peak MVICs, and integrated electromyography (IEMG) for each trial and subject.

Peak joint angles for knee flexion, hip flexion, and peak vertical and horizontal barbell displacement were obtained from the kinematic data through SkillSpector 1.3.2 software (Video4coach, Odense Sø, Denmark). Marker displacement and ground reaction force data were filtered using a fourth-order Butterworth filter using a Matlab routine (MathWorks, Inc.) with a 10 Hz cutoff frequency. To ensure that all subjects were compared between conditions, vertical barbell displacement was normalized by stature for each subject.

The normality and homogeneity of variances within the data were confirmed with the Shapiro-Wilk and Levenes tests, respectively. To test differences in muscle activity

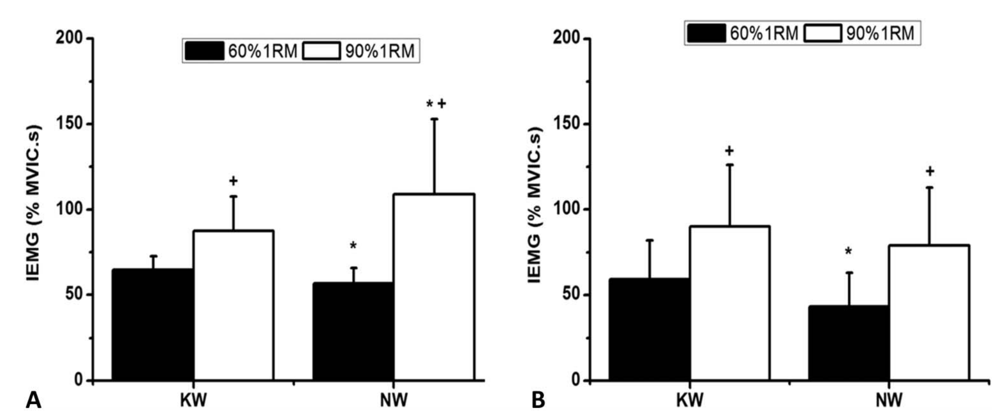

Figure 1. Mean and *SD* of integrated electromyography (IEMG) of (A) vastus lateralis (VL) and (B) gluteus maximus (GM), with (KW) and without knee wraps (NWs) at both 60% and 90% 1RM. *Significantly less than KW, $p \le 0.05$; +Significantly greater than 60%, $p \le 0.05$.

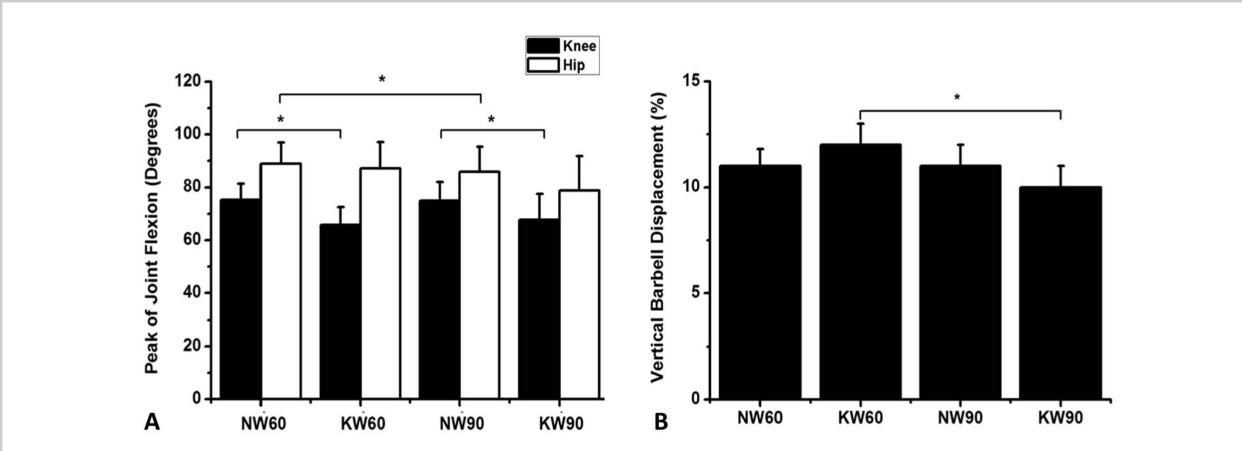

Figure 2. Mean and *SD* of kinematic variables for (A) peak angle of joint flexion and (B) normalized vertical barbell displacement, with (KW) and without knee wraps (NW) at both intensities (60 and 90% 1RM). $^*p \leq 0.05$.

(IEMG), RPE, and barbell displacement, 2 × 2 repeated-measures analyses of variances (ANOVAs) (wraps × intensity) were used. A 2 × 2 × 2 repeated-measures ANOVA (intensity × condition × peak joint angle) was used to determine differences in maximal joint flexion. Post hoc comparisons were performed with the Bonferroni's test. Cohen's formula for effect size (ES) was calculated, and the results were based on the following criteria: <0.35 trivial effect, 0.35–0.80 small effect, 0.80–1.50 moderate effect, and >1.5 large effect, for recreationally trained subjects (16). Test-retest reliability was calculated by intraclass correlation coefficient and ranged between 0.84 and 0.98 for all dependent variables. An alpha of 0.05 was used to determine statistical significance.

Results

Muscle Activity

The main reference for the level of muscle activation (concentric and eccentric phase) was the sEMG data (normalized by MVIC) from the back squat NWs.

There was a significant ($p < 0.001$) interaction of wraps × intensity for VL muscle activity. There was a significant decrease in NW60 ($p = 0.013$, ES = 0.93, Δ% = 12%) compared with KW60 and a significant increase in NW90 ($p = 0.037$, ES = 0.64, Δ% = 19.7%) compared with KW90. There was a significant increase at 90% 1RM when compared with 60% 1RM (KW: $p = 0.001$, ES = 1.51 and NW: $p < 0.001$, ES = 1.67, Δ% = 47.9%) (Figure 1A).

There was a significant ($p < 0.001$) main effect for GM muscle activity. There was a decrease in NW60 ($p = 0.014$, ES = 0.74, Δ% = 27.1%) compared with KW60. There were significant increases in GM muscle activity at 90% 1RM when compared with 60% 1RM (KW: $p < 0.001$, ES = 1.06, Δ% = 34.4% and NW: $p < 0.001$, ES = 1.29, Δ% = 45.6%) (Figure 1B).

Kinematic

There was a significant ($p < 0.001$) interaction of wraps × intensity for peak joint angle. For peak hip joint flexion angle, there was a significant difference between intensities (90% 1RM < 60% 1RM) only in the NWs condition ($p = 0.009$, ES = 0.60, Δ% = 1%) (Figure 2A). For peak knee joint flexion angle, there was a significant ($p < 0.001$) main effect for KWs, with decreases only in the NWs condition for both intensities: 60% 1RM ($p < 0.001$, ES = 1.38, Δ% = 13%) and 90% 1RM ($p = 0.018$, ES = 0.86, Δ% = 9.7%) (Figure 2A).

There was a significant ($p < 0.001$) main effect for normalized vertical barbell displacement, with significant differences (90% 1RM < 60% 1RM) to KWs condition ($p = 0.022$, ES = 2.0, Δ% = 16.6%) (Figure 2B). For horizontal barbell displacement, there were no significant differences between intensities or conditions. The values (mean ± *SD*) of horizontal barbell displacement for 60% 1RM were 3 ± 1.5 cm KWs and 3.2 ± 1.6 cm NWs and for 90% 1RM were 3.6 ± 1.4 cm KWs and 3 ± 1 cm NWs.

Rating of Perceived Exertion

There was a significant ($p < 0.001$) interaction of wraps × intensity for RPE. There were significant increase in RPE between 60 and 90% 1RM for each condition: KWs (4.7 ± 2 and 7.6 ± 1.8; $p < 0.001$, ES = 2.26, Δ% = 38.2%) and NWs (5 ± 1.5 and 8 ± 1.6; $p < 0.001$, ES = 1.5, Δ% = 37.5%). However, there were no significant differences between conditions (KW and NW).

Discussion

The purposes of this study were to measure the acute effects of KWs on knee and hip joint kinematics, sEMG, and RPE during the back squat exercise at 2 different intensities. The main results showed that there was an increase in VL and

GM muscle activation at 90% 1RM when compared with 60% 1RM for both conditions. Curiously, we also observed high VL activation only for NW at 90% 1RM when compared with KW. Considering the same external load (90% 1RM), in both conditions (NW and KW), probably the lower muscle activation during the KW may be because of the higher carryover effect (storage of elastic energy) produced by KWs (9). Thus, it seems that, considering the same load of training, the KW can help during the ascendant phase of the back squat, reducing the VL muscle effort. Additionally, the knee joint is innervated by large myelinated afferent fibers (group II afferents) that are activated by mechanical stimuli such as stretch and pressure as well as facilitating Ib inhibition of the VL motoneuron pool (17). The reduction of VL activation associated with the use of KWs may be related to high tissue pressure causing some level of neural inhibition. Also, the level of pressure might increase because of the strain produced by the KW across the full joint amplitude. Both the GM muscle activity and peak hip joint flexion did not differ between conditions at either intensity. This does not corroborate the results of Lake et al., (13) who showed that the use of KWs restricted motion around the hip joint, which caused a more upright posture and forced greater flexion at the knee joint.

The results of the horizontal barbell displacement were relatively small and expected, considering the level of peak joint flexion presented by all joints at both intensities (60 and 90% 1RM), although Lake et al. (13) had observed a reduction (39%) in the horizontal displacement of the barbell when KWs were worn. Accordingly, vertical barbell displacement showed an important difference only in KW conditions, and therefore it seems that the use of KWs in high-intensity loads may present a decrease in barbell displacement. The KW is known to cause considerable discomfort by creating a "wedge"-like physical barrier at the back of the knee joint, which might affect back squat technique (13).

Rating of perceived exertion is an important subjective tool for athletes, resistance-trained (well-versed in the back squat), and strength and conditioning coaches during exercise execution or training sessions (6,7,12). The considerable discomfort caused by KWs might mask the real RPE and affect this internal load control. No other study has measured RPE with or without knee wraps during the back squat exercise. However, we did not observe any differences in RPE after the back squat exercise between conditions (60 or 90% 1RM). These results may represent that the use of KWs does not affect the effort perception during the back squat exercise at different intensities, which could affect performance. In fact, the time of evaluation (3 minutes after the condition) was very short; however, all subjects could not use KWs for a long time considering the high level of occlusion, so our RPE results may represent a more reliable evaluation of this test in the practical application.

We recognize that this study has some limitations. The main limitation is that back squat performance was standardized by having all subjects squat until thighs were parallel to the ground. We also did not control skinfold of the sEMG detection area that is considered to be a low-pass filter. There may have been some inherent differences in the tightness between subjects. We also used a healthy nonathletic population, and our results are not generalizable to other conditions, populations, or athletes.

Practical Applications

The use of KWs promotes an effective carryover effect by reducing muscle activation of the VL around the knee joint when considered at the same intensity (90% 1RM). So, it seems that the use of KWs on the knees is not advised during the resistance training aiming a higher activation of muscles involved in the back squat exercise. However, the KWs may provide a mechanical advantage during a submaximal lifts reducing the amount of training adaptations that will occur under a given load and in turn having to increase the overload to get the same adaptations at the cost of added load on the joint structure. However, the KW may be a good strategy, in certain specific phases of periodization (i.e., next to the competition), aimed the familiarization with this kind of equipment widely used and effective to lifting high loads in competitions.

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