

Article

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

3 *Jonathan Sinclair¹, James Mann¹, George Weston¹, Nikolaj Poulsen¹, Christopher James*
4 *Edmundson¹, Ian Bentley¹ & Mark Stone¹*

5 *1. Centre for Applied Sport and Exercise Sciences, Faculty of Health and Wellbeing,*
6 *University of Central Lancashire, Lancashire, Preston, Lancashire, United Kingdom.*

7
8 **Correspondence Address:**

9 Dr. Jonathan Sinclair

10 Centre for Applied Sport & Exercise Sciences

11 Faculty of Health and Wellbeing

12 University of Central Lancashire

13 Preston

14 Lancashire

15 PR1 2HE.

16 **E-mail:** jksinclair@uclan.ac.uk

17 **Keywords:** Biomechanics; knee wraps; squat; kinetics; kinematics.

18

19 **Abstract**

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

41

42 **Introduction**

43 The back squat is perhaps the most frequently utilized resistance training exercise (1).
44 Because of its ability to recruit the quadriceps, gluteal, hamstrings, tibialis anterior, triceps
45 surae and lumbar muscles (2), it forms the basis of most strength and conditioning regimens
46 (3).

47

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

59

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

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

68

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

91

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

100

101 **Methods**

102 *Participants*

103 Fifteen male (age: 23.00 ± 3.47 years, stature: 181.93 ± 7.25 cm, mass: 85.83 ± 17.10 kg and
104 1RM back squat: 122.62 ± 24.43 kg) participants took part in the current study. Participants
105 were all practiced in the high bar back squat with a minimum of 2 years of experience in this
106 lift. All were free from musculoskeletal pathology at the time of data collection and provided
107 written informed consent. All procedures performed were in accordance with the ethical
108 standards of the institutional (STEMH ethical committee REF=458) and with the 1964
109 Helsinki declaration.

110

111 *Knee wraps/ sleeves*

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

126

127 *Procedure*

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

133

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

145

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

155

156 *Squat protocol*

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

171

172 *Processing*

173 Marker trajectories were digitized using Qualisys Track Manager and then exported as C3D
174 files. Kinematic parameters were quantified using Visual 3-D (C-Motion Inc, Gaithersburg,
175 USA). Marker data was smoothed using a low-pass Butterworth 4th order zero-lag filter at a
176 cut off frequency of 6 Hz (15). Kinematics of the hip, knee, ankle and trunk were quantified
177 using an XYZ cardan sequence of rotations and joint moments using newton-euler inverse
178 dynamics. All data were normalized to 100% of the squat via the first and second instances of
179 maximal hip flexion (15). A further time point at the mid-point of the lift that separated the
180 descent and ascent phases was identified using the lowest position of the bar (3). Three-

181 dimensional kinematic measures from the hip, knee, ankle which were extracted for statistical
182 analysis were 1) peak angle and 2) angular range of motion (ROM) from initiation to peak
183 angle. In addition, sagittal plane measures from the trunk of 1) peak angle and 2) angular
184 range of motion (ROM) were extracted. In addition to the above, the maximum velocity (m/s)
185 of the barbell during the ascent phase was quantified, as was the maximum anterior
186 displacement (m) of the barbell during the squat movement.

187

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

193

194 Hamstring, gluteus maximus, soleus and gastrocnemius forces were also quantified using
195 musculoskeletal modelling approaches (17). The hamstring and gluteus maximus forces were
196 calculated firstly using the hip extensor moment from inverse-dynamics and the hamstrings
197 and gluteus maximus cross-sectional areas, which determined the extent of the joint moment
198 attributable to each muscle (18). The hamstring muscle forces were then calculated by
199 dividing the hip extensor moment attributable to each muscle by the muscle moment arms
200 (19). The moment arms were obtained by fitting a 2nd order polynomial curve to the hip
201 flexion angle-hamstrings/ gluteus maximus moment arm data of Nemeth & Ohlsen, (19). In
202 addition, the gastrocnemius and soleus forces were calculated firstly by quantifying the ankle
203 plantarflexor force, which was resolved by dividing the dorsiflexion moment from inverse
204 dynamics by the Achilles tendon moment arm. The Achilles tendon moment arm was

205 calculated by fitting a 2nd order polynomial curve to the dorsiflexion angle-Achilles tendon
206 moment arm data of Self & Paine (20). Plantarflexion force accredited to the gastrocnemius
207 and soleus muscles was calculated via the cross-sectional area of this muscle relative to the
208 total volume of the triceps-surae (18).

209

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

218

219 The maximum extent to which the knee joint centre moved anteriorly and laterally during the
220 squat movement (m) was also calculated using Visual 3D. In addition, internal knee joint
221 forces were also calculated in accordance with using the joint force function within Visual 3D
222 (21). Furthermore, patellar tendon force was quantified using a model adapted from Janssen
223 et al., (22). The knee flexion moment quantified using inverse dynamics was divided by the
224 moment arm of the patellar tendon. The tendon moment arm was quantified by fitting a 2nd
225 order polynomial curve to the knee flexion angle-patellar tendon moment arm data provided
226 by Herzog & Read, (23). Patellofemoral stress was also quantified by dividing the
227 patellofemoral joint reaction force, by the patellofemoral contact area. The patellofemoral
228 reaction force was calculated by multiplying the adjusted quadriceps force (described above)

229 by a constant which was obtained via the below equation [eq1] using the data of van Eijden et
230 al., (16). Patellofemoral contact areas were obtained by fitting a 2nd order polynomial curve
231 to the sex specific knee flexion angle-patellofemoral contact area data of Besier et al., (24).

232

$$233 \text{ [eq1] constant} = (0.462 + 0.00147 * \text{knee flexion angle}^2 - 0.0000384 * \text{knee flexion angle} \\ 234 \text{ }^2) / (1 - 0.0162 * \text{knee flexion angle} + 0.000155 * \text{knee flexion angle}^2 - 0.000000698 * \\ 235 \text{ knee flexion angle}^3)$$

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

243

244 From the force plate, peak vertical GRF (N/kg) during the ascent phase of the lift was
245 extracted. The RFD of the vertical GRF (N/kg/s) was also calculated by obtaining the peak
246 increase in vertical GRF force between adjacent data points again using the first derivative
247 function within Visual 3D. In addition, the integral of the vertical, medio-lateral antero-
248 posterior GRF's (N/kg·s) were calculated during both the ascent and descent phases of the
249 lift, again using a trapezoidal function. Furthermore, the peak power applied to the centre of
250 mass (W/kg) during ascent phase was extracted using a product of the vertical GRF and the
251 vertical velocity of the model centre of mass within Visual 3D. The total lift duration was

252 also calculated using the time difference from the initiation to the end of each repetition, and
253 the absolute duration of the ascent/ descent phases (s) was also extracted as was the %
254 duration of the ascent/ descent phases, which were expressed as a function of the total lift
255 duration.

256

257 *Statistical analyses*

258 Descriptive statistics of means and standard deviations were obtained for each outcome
259 measure. Shapiro-Wilk tests were used to screen the data for normality. Differences in
260 biomechanical parameters between each of the four conditions were examined using one-way
261 repeated measures ANOVA's. Effect sizes were calculated using partial eta² (η^2). Effect
262 sizes were characterized as small = 0.01, medium = 0.06 and large = 0.14. In the event of a
263 significant main effect, post-hoc pairwise comparisons were conducted. In addition, the data
264 from participants' subjective ratings in relation to their preferred condition and also in
265 regards to the stability and comfort of each sleeve/ wrap were explored using Chi-Square (χ^2)
266 tests. Statistical actions were conducted using SPSS v25.0 (SPSS Inc., Chicago, USA) and
267 Statistical significance was accepted at the $P \leq 0.05$ level.

268

269 **Results**

270 *Kinetic and temporal parameters*

271 There was a significant main effect for the integral of the vertical GRF during the descent
272 phase ($P \leq 0.05$, $\eta^2 = 0.19$). Post-hoc pairwise comparisons showed that the vertical GRF
273 integral was significantly greater in the knee sleeve compared to the nothing condition
274 ($P=0.01$) and in the competition wrap in relation to the knee sleeve ($P=0.036$). There was also

275 a main effect for the extent of anterior bar displacement ($P \leq 0.05$, $\eta^2 = 0.25$). Post-hoc
276 pairwise comparisons showed that bar displacement was significantly greater in the nothing
277 condition compared to the competition ($P=0.004$) and training ($P=0.024$) wraps.

278

279 In addition, there was a significant main effect for the duration of the ascent phase ($P \leq 0.05$,
280 $\eta^2 = 0.35$). Post-hoc pairwise comparisons showed that this duration was significantly
281 greater in the nothing condition compared to the sleeve ($P=0.003$), competition wrap
282 ($P < 0.001$) and training wrap ($P=0.005$). There was a significant main effect for the
283 percentage duration of the ascent phase ($P \leq 0.05$, $\eta^2 = 0.35$). Post-hoc pairwise comparisons
284 showed that this duration was significantly greater in the nothing condition compared to the
285 sleeve ($P=0.01$), competition wrap ($P=0.002$) and training wrap ($P=0.01$). In addition, it was
286 also shown that percentage ascent phase duration was significantly greater in the knee sleeve
287 compared to the competition wrap. A significant main effect for the percentage duration of
288 the descent phase was also found ($P \leq 0.05$, $\eta^2 = 0.35$). Post-hoc pairwise comparisons
289 showed that this duration was significantly greater in the sleeve ($P=0.01$), competition wrap
290 ($P=0.002$) and training wrap ($P=0.01$) compared to the nothing condition. In addition it was
291 also shown that percentage descent phase duration was significantly greater in the
292 competition wrap compared to the knee sleeve ($P=0.009$).

293

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

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

301

302 **@@@TABLE 1 NEAR HERE@@@**

303

304 *Muscle forces*

305 There was a significant main effect for the integral of the quadriceps force during the ascent
306 phase ($P \leq 0.05$, $\eta^2 = 0.16$). Post-hoc pairwise comparisons showed that the integral was
307 significantly larger in the nothing condition ($P=0.035$) compared to the competition wrap. In
308 addition, there was a significant main effect for the integral of the gluteus maximus force
309 during the ascent phase ($P \leq 0.05$, $\eta^2 = 0.18$). Post-hoc pairwise comparisons showed that the
310 gluteus maximus integral was significantly larger in the nothing condition ($P=0.007$)
311 compared to the training wrap. There was also significant main effect for the integral of the
312 hamstring force during the ascent phase ($P \leq 0.05$, $\eta^2 = 0.18$). Post-hoc pairwise comparisons
313 showed that the hamstring integral was significantly larger in the nothing condition ($P=0.018$)
314 compared to the training wrap. There was a significant main effect for the integral of the
315 gastrocnemius force during the ascent phase ($P \leq 0.05$, $\eta^2 = 0.26$). Post-hoc pairwise
316 comparisons showed that the gastrocnemius integral was significantly larger in the nothing
317 ($P=0.016$) and sleeve ($P=0.012$) conditions compared to the competition wrap. Finally, there
318 was a significant main effect for the integral of the soleus force during the ascent phase
319 ($P \leq 0.05$, $\eta^2 = 0.25$). Post-hoc pairwise comparisons showed that the soleus integral was
320 significantly larger in the nothing ($P=0.015$) and sleeve ($P=0.012$) conditions compared to the
321 competition wrap.

322

323

@@@TABLE 2 NEAR HERE@@@

324

325 *Knee forces*

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

329

330

@@@TABLE 3 NEAR HERE@@@

331

332 *Kinematics*

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

337

338 There was a significant main effect for the sagittal plane knee ROM ($P \leq 0.05$, $\eta^2 = 0.20$).
339 Post-hoc pairwise comparisons showed that ROM was significantly larger in the knee nothing
340 condition compared to competition wrap ($P=0.04$) and in the knee sleeve in relation to the
341 competition ($P=0.03$) and training wraps ($P=0.004$). There was also a significant main effect
342 for the peak knee adduction angle ($P \leq 0.05$, $\eta^2 = 0.40$). Post-hoc pairwise comparisons

343 showed that peak knee adduction was significantly larger in the competition and training
344 wraps compared to the nothing ($P < 0.001$ & $P = 0.008$) and knee sleeve conditions ($p < 0.001$ &
345 $p = 0.005$). There was also a main effect for the knee coronal plane ROM ($P \leq 0.05$, $p\eta^2 = 0.37$).
346 Post-hoc pairwise comparisons showed that knee coronal plane ROM was significantly larger
347 in the competition and training wraps compared to the nothing ($P < 0.001$ & $P = 0.001$) and
348 knee sleeve conditions ($p = 0.013$ & $p = 0.012$).

349

350 There was a significant main effect for peak knee internal rotation ($P \leq 0.05$, $p\eta^2 = 0.31$). Post-
351 hoc pairwise comparisons showed that peak internal rotation was significantly larger in the
352 competition ($P = 0.001$) and training ($P < 0.0001$) wraps compared to the nothing condition.
353 There was also a main effect for the knee transverse plane ROM ($P \leq 0.05$, $p\eta^2 = 0.28$). Post-
354 hoc pairwise comparisons showed that knee transverse plane ROM was significantly larger in
355 the competition ($P = 0.001$) and training ($P = 0.001$) wraps compared to the nothing condition,
356 and in the training wrap ($P = 0.04$) compared to the sleeve condition.

357

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

365

366 There was a significant main effect for peak ankle eversion ($P \leq 0.05$, $\eta^2 = 0.28$). Post-hoc
367 pairwise comparisons showed that peak eversion was significantly larger in the sleeve
368 ($P=0.04$), training wrap ($P=0.002$) and competition wrap ($P=0.02$) compared to the nothing
369 condition. There was also a significant main effect for the coronal plane ankle ROM ($P \leq 0.05$,
370 $\eta^2 = 0.21$). Post-hoc pairwise comparisons showed that coronal plane ankle ROM was
371 significantly larger in the nothing condition compared to the competition ($P=0.007$) and
372 training wrap ($P=0.01$).

373

374 **@@@TABLE 4 NEAR HERE@@@**

375

376 *Subjective ratings*

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

389 significantly more participants found that the training wrap reduced comfort. For the ratings
390 of knee stability in the training wrap, 9 participants rated that this condition improved
391 stability, 4 no-change and 2 reduced stability. The chi-squared test was significant ($X^2= 5.20$,
392 $P<0.05$) and significantly more participants found that the training wrap provided improved
393 stability. For the subjective ratings of comfort in the competition wrap, 2 participants rated
394 that this condition improved comfort, 4 no-change and 9 reduced comfort. The chi-squared
395 test was significant ($X^2= 5.20$, $P<0.05$) and showed that significantly more participants found
396 that the competition wrap reduced comfort. For the ratings of knee stability in the
397 competition wrap, 11 participants rated that this condition improved stability, 2 no-change
398 and 2 reduced stability. The chi-squared test was significant ($X^2= 10.80$, $P<0.05$) and
399 significantly more participants found that the competition wrap provided improved stability.

400

401 **Discussion**

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

407

408 Previous analyses have shown that knee wraps influence performance parameters during the
409 back squat. Specifically, Lake et al., (3) showed that knee wraps significantly enhanced
410 mechanical power output during the ascent phase of the lift. The findings from the current
411 investigation do not support these observations as no significant alterations in power output

412 or GRF parameters during the ascent phase were evident as a function of wearing knee
413 wraps/ sleeves. Similarly, Lake et al., (3) showed that the lowering phase was performed
414 faster when knee wraps were worn, allowing elastic potential energy to be stored within the
415 knee wraps, increasing the vertical force applied to the centre of mass and augmenting the
416 power output during the ascent phase. The findings from this investigation do not agree with
417 those of Lake et al, (3), as the knee sleeve/ wraps increased the descent phase and decreased
418 the ascent phase duration, which may serve as the mechanical explanation for the lack of
419 improvements in performance parameters. The lack of agreement between analyses may be
420 due to the lower relative and absolute mass being lifted, alongside the participants' lack of
421 familiarity in using knee wraps/ sleeves. In contrast to the current study, in the investigation
422 of Lake et al., (3), athletes lifted at 80% of 1RM relative to a group maximum squat capacity
423 of 160.5 kg and had previous experience of squatting using knee wraps. The findings from
424 the current investigation therefore indicate that knee wraps/ sleeves may not mediate
425 improvements in performance parameters when lower masses are being lifted, in athletes who
426 are not accustomed to using them. This leads to the notion that the mechanical effects of knee
427 wraps/ sleeves may be mass (lifted) and experience dependant, and this is something that
428 future research should seek to full substantiate.

429

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

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

453

454 In agreement with the findings of Lake et al., (3) this study showed that knee wraps
455 significantly altered movement patterns during the back squat exercise, in relation to
456 squatting in the nothing condition. Importantly, sagittal plane knee ROM and the anterior
457 knee translation were statistically reduced in the knee wraps compared to the nothing
458 condition. It is likely that the reduced knee translation/ flexion ROM were responsible for the
459 reductions in horizontal bar displacement that were similarly shown in the knee wrap
460 conditions. Similar to Lake et al., (3) this observation is supported by the anterior-posterior
461 GRF integral during the descent phase, which was to be posteriorly orientated in both knee

462 wraps but directed anteriorly in the nothing condition and knee sleeve. The above
463 observations are supported by the subjective ratings of the knee wrap conditions, which
464 indicate that knee stability was significantly enhanced but with corresponding reductions in
465 perceived comfort. The above observations reinforce the propositions of both Lake et al., (3)
466 and Gomes et al., (6) who postulated that the discomfort mediated by knee wraps creates a
467 physical barrier about the knee joint. From an injury prevention perspective it could
468 nonetheless be interpreted that the decreases in anterior knee translation were important given
469 the attenuation of the peak knee shear force when wearing knee wraps. However, taking into
470 account knee wraps potential to diminish lower extremity muscle development and alter
471 natural squatting mechanics; further analyses are required before this could be properly
472 established.

473

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

482

483 Finally, like the knee wrap conditions the knee sleeve did not mediate improvements in
484 mechanical power output and statistically influenced the duration of the different phases of
485 the squat. However, unlike the knee wraps the knee sleeves did not significantly alter natural

486 squatting mechanics or influence muscle kinetics during the ascent phase in relation to the
487 nothing condition. It is proposed that this observation was mediated by the significant
488 improvements in both perceived comfort and stability that were noted in the knee sleeves in
489 relation to the nothing condition. Therefore, taking the above into account and the subjective
490 preference towards this condition, the findings from the current investigation indicate that
491 knee sleeves may be more efficacious for athletes who regularly utilize the back squat for
492 their training goals, although future longitudinal studies are required before this can be fully
493 substantiated.

494

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

502

503 In conclusion, the effects of knee wraps/ sleeves on the biomechanics of the barbell back
504 squat have received limited research attention. Therefore, the present study adds to the
505 current scientific knowledge, by providing a comprehensive evaluation regarding the effects
506 of knee wraps/ sleeves on kinetics, three-dimensional kinematics and muscle forces during
507 the squat. Importantly, knee wraps significantly reduced lower extremity muscle integrals
508 during the ascent phase, natural squatting mechanics in all three planes of rotation and also
509 reduced perceived comfort. However, knee sleeves were conversely able to mediate

510 significant improvements in both perceived comfort and stability but did not significantly
511 alter natural squatting mechanics or influence muscle kinetics during the ascent phase.
512 Taking into account the potential of knee wraps to diminish lower extremity muscle
513 development; knee sleeves may be more efficacious for athletes who regularly utilize the
514 back squat for their training goals, although further longitudinal analyses are required before
515 this can be fully established.

516

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521

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- 603
- 604

Table 1: Kinetic and temporal parameters (Mean \pm 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 <i>ABC</i>	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 <i>ABC</i>	5.20	49.91	5.64	47.56	5.73	48.72	5.14	*
Descent percent duration (%)	48.65 <i>ABC</i>	5.20	50.09	5.64	52.44	5.73	51.28	5.14	*
Knee anterior translation (cm)	20.50 <i>B</i>	2.87	20.49	3.56	19.07	4.06	19.93	4.45	*
Knee lateral translation (cm)	13.41 <i>BC</i>	3.04	13.85 <i>BC</i>	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 <i>A</i>	2.91	13.00	2.70	14.17 <i>A</i>	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 \pm 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 <i>B</i>	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 <i>C</i>	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 <i>C</i>	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 <i>B</i>	3.09	6.85 <i>B</i>	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 <i>B</i>	6.61	14.62 <i>B</i>	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 \pm 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 <i>B</i>	2.15	7.62 <i>B</i>	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 \pm SD) as a function of each experimental condition.

	Nothing		Sleeve		Competition wrap		Training wrap		
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
<u>Trunk (Sagittal plane)</u>									
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	
<u>Hip (Sagittal plane + = flexion)</u>									
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	
<u>Hip (Coronal plane + = adduction)</u>									
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	
<u>Hip (Transverse plane + = internal rotation)</u>									
Peak internal rotation (°)	10.80 <i>BC</i>	13.19	11.50 <i>BC</i>	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	
<u>Knee (Sagittal plane + = flexion)</u>									
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	*
<u>Knee (Coronal plane + = adduction)</u>									
Peak adduction (°)	8.64 <i>BC</i>	5.38	9.27 <i>BC</i>	6.86	17.65	6.76	17.44	6.55	*
ROM (°)	6.87 <i>BC</i>	4.25	7.41 <i>BC</i>	5.64	14.81	7.25	15.03	6.51	*
<u>Knee (Transverse plane + = internal rotation)</u>									
Peak internal rotation (°)	19.81 <i>BC</i>	9.32	24.26	15.79	31.45	12.70	29.62	10.59	*
ROM (°)	22.95 <i>BC</i>	11.61	24.86 <i>C</i>	18.82	34.17	12.41	33.12	10.59	*
<u>Ankle (Sagittal plane + = dorsiflexion)</u>									
Peak dorsiflexion (°)	27.72 <i>B</i>	5.65	27.46 <i>B</i>	6.04	23.96	5.98	25.91	7.29	*
ROM (°)	28.29 <i>BC</i>	5.64	27.89 <i>B</i>	5.76	24.04	6.55	26.28	6.68	*
<u>Ankle (Coronal plane + = inversion)</u>									
Peak eversion (°)	-9.14 <i>ABC</i>	5.13	-11.43	6.90	-14.31	7.13	-12.23	4.84	*
ROM (°)	9.25 <i>BC</i>	4.28	11.08	5.61	12.72	4.81	12.38	3.53	*
<u>Ankle (Transverse plane + = internal rotation)</u>									
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