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1 **Effects of a prophylactic knee sleeve on ACL loading during sport specific movements:**

2 **Implications for injury prevention.**

3 *Jonathan Sinclair¹ & Paul John Taylor²*

4 *1. Centre for Applied Sport and Exercise Sciences, School of Sport and Wellbeing,*
5 *Faculty of Health and Wellbeing, University of Central Lancashire, Lancashire, UK.*

6 *2. School of Psychology, Faculty of Science and Technology, University of Central*
7 *Lancashire, Lancashire, UK.*

8 **Correspondence Address:**

9 Dr. Jonathan Sinclair

10 Centre for Applied Sport Exercise and Nutritional Sciences

11 School of Sport and Wellbeing

12 Faculty of Health and Wellbeing

13 University of Central Lancashire

14 Preston

15 Lancashire

16 PR1 2HE.

17 **e-mail:** jksinclair@uclan.ac.uk

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21

22 **Abstract**

23 The aim of the current investigation was to investigate the effects of a prophylactic knee
24 sleeve on ACL loading parameters linked to the aetiology of injury in recreational athletes.
25 Thirteen male recreational athletes performed run, cut and single leg hop movements under
26 two conditions (prophylactic knee sleeve/ no-sleeve). Biomechanical data was captured using
27 an eight-camera 3D motion capture system and a force platform. ACL loading parameters
28 were examined using 2 (sleeve)*3 (movement) repeated measures ANOVA's. The results
29 showed that both average and instantaneous ACL load rates were significantly reduced when
30 wearing the knee sleeve in the hop (sleeve = 612.45/ 1286.39N/kg/s & no-sleeve = 743.91/
31 1471.42 N/kg/s) and cut (sleeve = 222.55/ 1058.02 N/kg/s & no-sleeve = 377.38/ 1183.01
32 N/kg/s) movements. Given the biomechanical association between ACL loading and the
33 aetiology of ACL injuries, it is proposed that athletes may be able to attenuate their risk from
34 injury during cut and hop movements through utilization of a prophylactic knee sleeve.

35

36 **Introduction**

37 Whilst engaging in physical activity and sport is known to mediate a plethora of
38 physiological benefits (Schnohr et al., 2015), participation in sport is also associated with a
39 high risk from injury (Lauersen et al., 2014). Injuries to the anterior cruciate ligament (ACL)
40 are increasing common in those who engage in recreational/ competitive sports activities
41 (Boden et al., 2009). ACL pathologies are extremely serious leading to a long term cessation
42 from training/ competition (Arderm et al., 2011). Furthermore, ACL injury is typically
43 associated with chronic knee discomfort ultimately leads to forced retirement from

44 competition in many cases (Myklebust & Bahr, 2004). Importantly Roos et al., (1995)
45 confirmed this assertion in that the findings from their investigation determined that only 30
46 % of football players remained active 3 years after suffering an ACL injury. In addition, even
47 following full functional recovery from injury, athletes habitually fail to return to pre-injury
48 levels of performance and it has been demonstrated that statistically significant decrements in
49 performance are evident in relation to non-injured control athletes (Carey et al., 2006).

50

51 In addition to the pain/discomfort associated with knee ligament pathologies, more serious
52 long term clinical repercussions are associated with ACL injuries. Athletes who experience
53 ACL injury are up to 10 times more likely to develop early-onset degenerative knee
54 osteoarthritis in comparison to non-injured controls (Øiestad et al., 2009). This ultimately
55 serves to reduce participation in sports activities but also facilitates chronic pain and
56 disability in later life (Ajuied et al., 2014). Clinical studies in the US have shown that over
57 175,000 ACL reconstruction surgeries are conducted every year, with directly associated
58 direct costs in excess of over \$2 billion and total allocated costs of \$3.4 billion (Gottlob et al.,
59 1999).

60

61 ACL injuries in athletes are habitually non-contact in nature, in that ligamentous pathology
62 occurs in the absence of any physical interaction between athletes (Boden et al., 2009).
63 Biomechanically, ACL injuries occur when excessive loading is experienced by the ACL
64 itself (Smith et al., 2012). In athletic populations, research has revealed that non-contact ACL
65 injuries predominantly occur in the period immediately preceding foot strike when the knee is
66 in a position close to full extension in sports tasks involving sudden decelerations, landings
67 and pivoting maneuvers (Olsen et al., 2004). It has been demonstrated that most non-contact

68 ACL injuries occur in activities that involve single-limb decelerations/ landings (Boden et al.,
69 2009).

70

71 Prophylactic knee bracing is extensively utilized in athletic populations in order to reduce the
72 high risk from knee injuries during training/ competition (Sinclair et al., 2017). Prophylactic
73 knee braces are now extremely common and aim to provide protection from injury whilst also
74 being minimally restrictive to the wearer, thus allowing full range of knee motion during their
75 sports specific movements. The majority of research investigating the efficacy of knee
76 bracing in relation to the ACL has examined their effects in those with pre-existing
77 pathologies (either in those with ACL deficiencies or following ACL reconstruction) and
78 there is only limited information concerning their protective effects in healthy athletes.
79 Clinical research into the effects of prophylactic knee bracing on ACL injury rates in athletes
80 has shown in two studies that prophylactic knee bracing did not significantly attenuate the
81 incidence of ACL injuries in athletic populations (Jackson et al., 1991; Sitler et al., 1990). In
82 addition, aetiological investigations have examined the effects of knee bracing on the
83 causative mechanisms of ACL injuries using cadaver based analyses. Erickson et al., (1993)
84 examined the ability of prophylactic knee braces to reduce or limit medial collateral ligament
85 (MCL) and ACL strain under dynamic loading conditions. Their results showed that the
86 braces did not significantly reduce the strain experienced by either the MCL or the ACL.
87 There are currently no biomechanical investigations examining the effects of prophylactic
88 devices on ACL loading magnitudes linked to the aetiology of injury during sport movements
89 using human participants. Furthermore, many prophylactic knee braces that have been
90 examined in previous biomechanical literature concerning the knee ligaments have featured
91 medial and lateral vertical hinges, thus questionable as to whether they are truly non-
92 restrictive during non-linear sports movements (Raja & Dewan, 2011).

93

94 Therefore the aim of the current investigation was to investigate the effects of a minimally
95 restrictive prophylactic knee sleeve on ACL loading parameters linked to the aetiology of
96 injury in recreational athletes. Research of this nature may provide important clinical
97 information regarding the potential role of prophylactic knee sleeves for the prevention of
98 ACL injuries in recreational athletes.

99

100 **Methods**

101 *Participants*

102 Thirteen male recreational athletes (age = 23.55 ± 1.77 years, height = 1.79 ± 0.06 m, mass =
103 71.48 ± 7.56 kg) were recruited to for this study. All participants were free from lower
104 extremity pathology at the time of data collection and had not suffered from a knee injury in
105 the last five years. Written informed consent was provided in accordance with the declaration
106 of Helsinki. The procedure was approved by a university ethics committee (REF 291).

107

108 *Procedure*

109 Participants were required to complete five repetitions of three sports specific movements';
110 jog, cut and single leg hop, with and without presence of a prophylactic knee sleeve (Trizone,
111 DJO USA). To prevent any order effects in the experimental data the manner that participants
112 performed in each movement/ sleeve condition was counterbalanced. Kinematics and ground
113 reaction forces data were synchronously collected using an analogue to digital interface
114 board. Kinematic data was captured at 250 Hz via an eight camera motion analysis system

115 (Qualisys Medical AB, Goteburg, Sweden), and ground reaction forces via an embedded
116 piezoelectric force platform (Kistler, Kistler Instruments Ltd., Alton, Hampshire) which
117 sampled at 1000 Hz. Dynamic calibration of the motion capture system was performed before
118 each data collection session.

119

120 Lower extremity segments were modelled in 6 degrees of freedom using the calibrated
121 anatomical systems technique (Cappozzo et al., 1995). To define the segment co-ordinate
122 axes of the foot, shank and thigh, retroreflective markers were placed bilaterally onto 1st
123 metatarsal, 5th metatarsal, calcaneus, medial and lateral malleoli, medial and lateral
124 epicondyles of the femur. To define the pelvis segment further markers were posited onto the
125 anterior (ASIS) and posterior (PSIS) superior iliac spines. Carbon fiber tracking clusters were
126 positioned onto the shank and thigh segments. The foot was tracked using the 1st metatarsal,
127 5th metatarsal and calcaneus markers and the pelvis using the ASIS and PSIS markers. The
128 centers of the ankle and knee joints were delineated as the mid-point between the malleoli
129 and femoral epicondyle markers, whereas the hip joint centre was obtained using the
130 positions of the ASIS markers. Static calibration trials were obtained allowing for the
131 anatomical markers to be referenced in relation to the tracking markers/ clusters.

132

133 Data were collected during run, cut and jump movements according to below:

134

135 *Run*

136 Participants ran at 4.0 m/s \pm 5% and struck the force platform with their right (dominant) limb
137 (Sinclair et al., 2014). Participants commenced their movement a minimum of 20 feet away

138 from the force platform. The average velocity of running was monitored using infra-red
139 timing gates (SmartSpeed Ltd UK). The stance phase of running was defined as the duration
140 over > 20 N of vertical force was applied to the force platform.

141

142 *Cut*

143 For the cut movement participants used an approach velocity of $4.0 \text{ m/s} \pm 5\%$ and struck the
144 force platform with their right (dominant) limb (Sinclair et al., 2015). Participants were
145 required change direction to the opposite side at a 45° angle. As with the run movement
146 participants commenced their movement a minimum of 20 feet away from the force platform.
147 Cut angles were measured from the centre of the force plate and the corresponding line of
148 movement was delineated using masking tape so that it was clearly evident to participants.
149 The stance phase of the cut-movement was similarly defined as the duration over > 20 N of
150 vertical force was applied to the force platform.

151

152 *Jump*

153 Participants completed counter movement vertical jumps in which they were required to use
154 full arm swing and also to commence and land the jump on the force platform. The landing
155 phase of the jump movement was quantified and was considered to have begun when >20 N
156 of vertical force was applied to the force platform and ended at point of maximum knee
157 flexion.

158

159 *Processing*

160 A musculoskeletal modelling approach was utilized to quantify ACL loading during the lunge
161 movement. To accomplish this we firstly had to quantify the tibia-anterior shear force
162 (TASF), which was undertaken using a modified version of the model described in detail by
163 Devita & Hortobagyi, (2001). Our model differed only in that gender specific estimates of
164 posterior tibial plateau slope (Hohmann et al., 2011), hamstring-tibia shaft angle (Lin et al.,
165 2009) and patellar tendon-tibia shaft angle (Nunley et al., 2003) were utilized.

166

167 ACL loading was determined as the sum of ACL forces caused by the TASF, transverse
168 plane knee moment, and coronal plane knee moment in accordance with the below equation.

169

$$170 \text{ ACL load} = (F100 / 100 * \text{TASF}) + (F10TV / 10 * \text{transverse plane knee moment}) + (F10CR$$
$$171 \quad \quad \quad / 10 * \text{coronal plane knee moment})$$

172

173 The components of the above equation were obtained using the data described by Markolf et
174 al., (1995), who examined ACL forces in vitro when a 100 N TASF (*F100*) was applied to
175 cadaver knees from 0-90° of knee flexion. ACL forces were also measured when additional
176 torques of 10 Nm in the coronal (*F10CR*) and transverse (*F10TV*) planes were combined with
177 the 100 N TASF from 0-90° of knee flexion.

178

179 All force parameters were normalized by dividing the net values by body mass (N/kg). From
180 the musculoskeletal models peak ACL was extracted. In addition ACL average and
181 instantaneous load rates (N/kg/s) were quantified. Average load rate was obtained by dividing

182 the peak ACL force by the duration over which the force occurred and instantaneous load rate
183 was quantified as the peak increase in force between adjacent data points.

184

185 *Statistical analyses*

186 Descriptive statistics of means, standard deviations (*SD*) and 95% confidence intervals (95%
187 CI) were obtained for each outcome measure. Shapiro-Wilk tests were used to screen the data
188 for normality. Differences in ACL parameters were explored using 2 (Sleeve) x 3
189 (Movement) repeated measures analysis of variance (ANOVA) with statistical significance
190 accepted at the $p \leq 0.05$ (Sinclair et al., 2013). Post-hoc analysis on significant main effects
191 were undertaken in the form of pairwise comparisons. Significant interactions were further
192 evaluated by performing simple main effect examinations on each level of the interaction, in
193 the event of a significant simple main effect pairwise comparisons were performed. Effect
194 sizes were calculated using partial η^2 ($p\eta^2$). All statistical actions were conducted using
195 SPSS v23.0 (SPSS Inc, Chicago, USA).

196

197 **Results**

198 Table 1 displays ACL loading parameters as a function of the knee sleeve and different
199 movements. The findings show that ACL loading was influenced as a function of both the
200 knee sleeve and the different movements.

201

202 **@@@ TABLE 1 NEAR HERE @@@**

203

204 For peak ACL force a significant main effect ($P < 0.05$, $\eta^2 = 0.70$) was observed for
205 'movement', which showed that peak ACL force was significantly larger in the hop
206 movement in comparison to the run ($P = 0.00000001$) and cut ($P = 0.0002$) conditions and in the
207 cut movement compared to the run ($P = 0.004$).

208

209 For average load rate a significant main effect ($P < 0.05$, $\eta^2 = 0.22$) was noted for 'sleeve'.
210 With average load rate being significantly reduced in the sleeve condition. In addition there
211 was also a significant main effect ($P < 0.05$, $\eta^2 = 0.49$) for 'movement', which showed that
212 average load rate was significantly larger in the hop movement in comparison to the run
213 ($P = 0.001$) and cut ($P = 0.0003$) conditions. Finally, a significant sleeve*movement interaction
214 ($P < 0.05$, $\eta^2 = 0.19$) was also observed. Further analysis using simple main effects showed in
215 the cut ($P = 0.004$, $\eta^2 = 0.40$) and hop ($P = 0.03$, $\eta^2 = 0.25$) movements that the average ACL
216 load rate was significantly reduced in the sleeve condition. However, in the run movement
217 ($P = 0.46$, $\eta^2 = 0.03$) no differences were found between the sleeve and no-sleeve conditions.

218

219 For instantaneous load rate a significant main effect ($P < 0.05$, $\eta^2 = 0.25$) was noted for
220 'sleeve', load rate being significantly reduced in the sleeve condition. In addition there was
221 also a significant main effect ($P < 0.05$, $\eta^2 = 0.65$) for 'movement', which showed that
222 instantaneous load rate was significantly larger in the hop movement in relation to the run
223 ($P = 0.00000007$) and cut ($P = 0.003$) conditions and in the cut movement compared to the run
224 ($P = 0.0001$). Finally, a significant sleeve*movement interaction ($P < 0.05$, $\eta^2 = 0.23$) was also
225 observed. Further analysis using simple main effects showed in the cut ($P = 0.02$, $\eta^2 = 0.27$)
226 and hop ($P = 0.03$, $\eta^2 = 0.26$) movements that the instantaneous ACL load rate was

227 significantly reduced in the sleeve condition. However, in the run movement ($P=0.56$, $p\eta^2 =$
228 0.02) no differences were found between the sleeve and no-sleeve conditions.

229

230 **Discussion**

231 The aim of the current investigation was to examine the effects of a prophylactic knee sleeve
232 on ACL loading parameters linked to the aetiology of injury in recreational athletes. To our
233 knowledge this represents the first investigation to quantitatively analyze the effects of
234 prophylactic knee sleeves on ACL loading during sports specific movements.

235

236 Importantly the current investigations showed that ACL average and instantaneous load rates
237 were significantly reduced during the cut and hop movements when wearing the prophylactic
238 sleeve. This observation is an interesting one in that the prophylactic knee sleeve served to
239 mediate significant reductions in ACL loading parameters in the cut and hop movements, yet
240 in the run condition there were no statistical improvements. As stated previously the
241 mechanical aetiology of ACL injury in athletic populations is caused by excessive loading is
242 of the ACL itself (Smith et al., 2012). Therefore, given the increased rate at which the ACL
243 was loaded in the no-sleeve condition, this observation may be important clinically. It can be
244 conjectured that ACL injury risk during specific athletic movements through may be
245 attenuated through utilization of prophylactic knee sleeve.

246

247 An additional important observation from the current study is that, ACL loading parameters
248 were all significantly greater in the cut and hop movements in comparison to the run
249 condition. This observation agrees with previous conjecture which indicates that ACL injury

250 risk is greatest in movements such as the cut and hop conditions which feature significant
251 decelerations, landings and pivoting motions (Olsen et al., 2004). It is hypothesized that this
252 finding relates to the ballistic nature of cut and leg hop conditions in relation to the running,
253 which increase TASF and thus resistive ligamentous loading (Devita & Hortobagyi, 2001).
254 Because the ACL injuries are linked to excessive loading of the ligament itself (Smith et al.,
255 2012), the current study indicates that athletic disciplines which feature a significant number
256 of cut and hop motions may place athletes at increased risk from ACL injury.

257

258 In conclusion, although previous investigations have examined the efficacy of prophylactic
259 knee bracing, our current knowledge regarding their effects on the ACL in functional athletic
260 movements is limited. As such the current work addresses this by examining the influence of
261 a prophylactic knee sleeve on ACL loading parameters during run, cut and jump movements.
262 The current study importantly showed that ACL loading parameters were significantly
263 reduced in the hop and cut movements whilst wearing the knee sleeve. In addition it was also
264 revealed that the cut and hop movements were associated with significantly greater ACL
265 loading in relation to the run condition. Given the biomechanical association between ACL
266 loading and the aetiology of ACL injuries, it is proposed that athletes may be able to
267 attenuate their risk from injury during cut and hop movements through utilization of a
268 prophylactic knee sleeve.

269

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Table 1: ACL loading parameters as a function of the knee sleeve and different movements.

	Run						Cut						Hop					
	No-Sleeve			Sleeve			No-Sleeve			Sleeve			No-Sleeve			Sleeve		
	Mean	<i>SD</i>	95% CI	Mean	<i>SD</i>	95% CI	Mean	<i>SD</i>	95% CI	Mean	<i>SD</i>	95% CI	Mean	<i>SD</i>	95% CI	Mean	<i>SD</i>	95% CI
Peak ACL force (N/kg)	12.57	1.92	10.62-12.52	12.49	3.37	10.71-14.06	14.34	2.36	13.17-15.52	14.20	2.98	12.72-15.68	18.76	4.43	16.55-20.96	18.67	2.58	17.39-19.96
ACL load rate (N/kg/s)	267.76	146.95	164.68-310.83	263.57	259.76	144.40-402.75	377.38	222.73	266.62-488.14	222.55	62.17	191.64-253.47	743.91	532.24	479.23-1008.59	612.45	422.87	402.17-822.74
ACL instantaneous load rate (N/kg/s)	813.00	228.39	699.42-926.57	810.66	327.87	677.62-1003.71	1183.01	335.54	1016.15-1349.96	1058.02	270.70	923.40-1192.64	1471.42	544.19	1200.79-1742.04	1286.39	344.11	1115.27-1457.52