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Knee flexion strength is significantly reduced following competition in semi-professional Australian Rules football athletes: Implications for injury prevention programs

Paula C. Charlton, Benjamin Raysmith, Martin Wollin, Simon Rice, Craig Purdam, Ross A. Clark, Michael K. Drew

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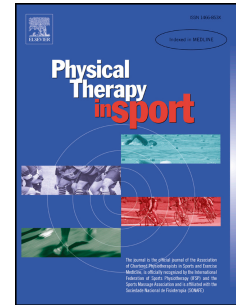
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1 **Knee flexion strength is significantly reduced following competition in semi-professional**
2 **Australian Rules Football athletes: Implications for injury prevention programs**

3
4 Paula C. Charlton^{1*}, Benjamin Raysmith¹, Martin Wollin¹, Simon Rice², Craig Purdam¹, Ross A.
5 Clark³ & Michael K. Drew^{1,4}

6 ¹Department of Physical Therapies, Australian Institute of Sport (AIS), Canberra, Australia

7 ²Australian Capital Territory Academy of Sport (ACTAS), Canberra, Australia

8 ³School of Health and Sport Science, Faculty of Science, Health, Engineering and Education,
9 University of the Sunshine Coast, Australia

10 ⁴Australian Collaboration for Research into Injury in Sport and its Prevention (ACRISP), Federation
11 University Australia, Ballarat, Australia

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22 ***Corresponding Author:**

23 Dr Paula Charlton, DClinPhysio, MPhysio(Musc), MPhysio(Sports), MEx Sc, PhD Candidate
24 Senior Sports Physiotherapist
25 c/o AIS Physical Therapies
26 Australian Institute of Sport
27 Leverrier Cr, Bruce ACT 2614,
28 Australia
29 Tel: +61 2 6214 1253
30 Fax: +61 2 6214 1753
31 Email: paula.charlton@ausport.gov.au

1 **Knee flexion strength is significantly reduced following competition in semi-professional**
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11

12 Abstract

13 **Objectives:** To evaluate strength and flexibility measures pre- and post- Australian Football (AF)
14 competition to determine their potential utility as secondary prevention measures.

15 **Design:** Cohort study

16 **Setting:** Semi-professional AF club

17 **Participants:** Ten male AF athletes (mean \pm SD; age, 21.3 \pm 2.2years; height, 186.1 \pm 6.3cm; weight,
18 83.5 \pm 8.6kg)

19 **Main Outcome Measures:** Maximal unilateral isometric knee flexion strength performed in 45
20 degrees of hip flexion and 30 degrees of knee flexion, flexibility measures of hip and knee extension
21 and ankle dorsiflexion. All outcome measures were evaluated pre-match to determine baseline
22 measurements and repeated acutely post-match and at 26, 50 and 74 hours following. Comparisons
23 were made between baseline measures and all other time points.

24 **Results:** Knee flexion strength was significantly reduced at a group level acutely (-122.8N, 95%CI -
25 156.2 to -89.4, $p=0.000$) and at 26 hours (-89.6N, 95%CI -122.9 to -56.2, $p=0.000$) following
26 competition. Hamstring flexibility was significantly reduced at all time periods following competition
27 (all $p<0.05$), however these values were not clinically meaningful.

28 **Conclusions:** Knowledge that unilateral isometric knee flexion strength returns to pre-competition
29 levels by 50 hours following match-play in AF athletes is valuable for planning recovery time frames
30 and may inform implementation of secondary prevention strategies.

31 Highlights:

- 32 • Maximal voluntary isometric knee flexion strength is significantly reduced at 26 hours following
33 competitive match-play in adult semi-professional AF athletes

- 34 • Knowledge that restoration of maximal isometric knee flexion strength occurred by 50 hours post-
35 match at the group level may be used to monitor recovery and assist in planning of subsequent
36 training sessions
- 37 • Information regarding knee flexion strength recovery following match-play may be particularly
38 pertinent for monitoring athletes with a past-history of hamstring strain

39 **Keywords:** Secondary prevention; athlete monitoring; hamstring strain injury

40

41

42

43 **Introduction**

44 A large body of literature has been dedicated to understanding potential risk factors associated with
45 hamstring strain. A number of non-modifiable risk factors have been identified including increased
46 player age, indigenous race and a past history of both hamstring and other injuries (Verrall,
47 Slavotinek, Barnes, 2001). Other known risk factors, such as hip, knee and ankle flexibility have been
48 reported (Bradley & Portas, 2007; Gabbe, Bennell, Finch, 2006; Witvrouw, Danneels, Asselman,
49 2003). Hamstring strength deficits have also been consistently identified (Orchard, Marsden, Lord,
50 1997), and are modifiable. However, despite this, high rates of hamstring strain have been stable and
51 hamstring strain remains the most common and prevalent injury reported since the inception of injury
52 surveillance in the Australian Football League (Orchard, Seward, Orchard, 2013). One reason for this
53 might be that identified strength deficits have been reported as single measures usually conducted in
54 the pre-season (Opar, Williams, Timmins, 2014; Orchard et al. 1997) and are unable to reflect weekly
55 fluctuations that might occur due a variety of reasons such as the accumulation of fatigue. It has been
56 reported that high-intensity activities are significantly reduced in the final stages of competitive
57 match-play, across several matches for intermittent team sports (Bradley, Sheldon, Wooster, 2009;
58 Skykes, Twist, Nicholas, 2011), possibly associated with match-induced fatigue (Black, Gabbett,
59 Naughton, 2016).

60 Knowledge of weekly fluctuations of hamstring strength and lower limb flexibility profile changes
61 throughout the in-season period, particularly in response to match-play, may contribute to a better
62 understanding of the aetiology of hamstring injuries. It is currently uncertain as to whether potential
63 variations may elucidate athletes at risk of injury or maladaptation to the completed workloads. In
64 this context, routine monitoring of strength and lower limb flexibility may present an opportunity for
65 secondary prevention (Jacobsson & Timpka, 2015). Secondary prevention is one of three sub-
66 categories (primary, secondary and tertiary) of preventative measures aimed at preventing a specific
67 pathology. Secondary prevention measures are implemented before pathology has caused long-term
68 disability where sub-clinical signs of pathology may exist (Jacobsson & Timpka, 2015), in practice
69 this refers to early detection and interventions addressing clinical signs which may result in injury.

70 Recently, a simple and inexpensive method of measuring isometric knee flexion strength, namely
71 externally fixed dynamometry, has been evaluated in response to competitive match-play in junior
72 elite soccer athletes (Wollin, Thorborg, Pizzari, 2016). Results demonstrated significant reductions in
73 strength compared with pre-match measures immediately and at 24 hours following match-play. This
74 is yet to be investigated in AF, where, similarly to soccer, match running volumes are large and the
75 rate of hamstring strain is high (Bradley & Noakes, 2013; Woods, Hawkins, Maltby, 2004).
76 Information on recovery of strength and flexibility measures following Australian Football match-
77 play would be able to inform sports specific injury prevention practices.

78 The aim of this study was to evaluate the effect of competitive match-play on measures of isometric
79 knee flexion strength and lower limb flexibility in semi-professional AF athletes. Knowledge of
80 timeframes of recovery of knee flexion strength and ankle, hip and knee flexibility using clinically
81 feasible tools could assist planning of training and inform implementation of in-season monitoring
82 strategies in high-risk cohorts as a component of secondary prevention.

83 **Methods**

84 This study was a cohort study using repeated-measures which assessed the responsiveness of lower
85 limb strength and flexibility measures to competitive AF match-play. Baseline measures were
86 conducted pre-match (within four hours of the commencement of competition) and were re-assessed
87 acutely post-match (within 30 minutes), and again at 26, 50 and 74 hours following competition.

88 Participants (n=10, n=20 limbs) were recruited from a single sub-elite Australian football team in the
89 North East Australian Football League Competition, a senior, semi-professional AF competition,
90 during the 2016 season. Each participant was provided with a detailed verbal and written explanation
91 of the full experimental procedure. All participants provided written informed consent. This study was
92 approved by the Australian Institute of Sport Ethics Committee (Approval Number: 20160805) and
93 was conducted in accordance with the Helsinki Declaration. Participants were included if they were
94 pain and injury free at the time of testing, reported no lower limb injuries in the month prior and had
95 completed a minimum of one month of full training and match-play prior to testing. Participants were

96 excluded if they sustained an injury during the match in question or did not participate in ≥ 25 minutes
97 on the field for each of the four quarters of the match.

98

99 Prior to baseline testing, it was ensured that all participants were familiarised with the experimental
100 procedure. Physical outcome measurements included bilateral maximum voluntary isometric
101 contraction (MVIC) of the knee flexors and lower limb flexibility. Unilateral MVIC of the knee
102 flexors was evaluated using an externally-fixed dynamometer and strength was recorded in Newtons
103 (N) using a reliable protocol that has been previously described in detail (Wollin, Purdam, Drew,
104 2015). This test is performed with the athlete in prone with the hip in 45 degrees of flexion and the
105 shank parallel to the ground. This protocol has demonstrated a 5% standard error of measurement
106 (SEM) and 14% minimal detectable change (MDC) (Wollin et al. 2015). Bilateral lower limb
107 flexibility outcome measurements included ankle dorsiflexion range of motion assessed using the
108 knee to wall (KTW) test (Dennis, Finch, Elliot, 2008), hip extension range of motion using a modified
109 version of the Thomas Test (MTT) (Dennis et al. 2008) and hamstring flexibility using the active knee
110 extension (AKE) (Wollin et al. 2016) test. These tests were specifically chosen due to their
111 identification as potential hamstring strain injury risk factors having been previously associated with
112 hamstring strain injury in team sport populations. Both MTT and AKE were measured using a bi-level
113 inclinometer (Isomed Inc, Kirkland WA, USA). The reliability and procedures of these tests have also
114 been previously described in detail (Dennis et al. 2008; Wollin et al. 2016). Briefly, all three tests
115 have previously demonstrated excellent intra-rater reliability in healthy adult populations: KTW (ICC
116 = 0.98, SEM 0.3cm, MDC 0.8 cm) (Dennis et al. 2008), the modified MTT (ICC = 0.97, SEM 1.3°,
117 MDC 3.6°) (Dennis et al. 2008) and AKE (ICC = 0.91 - 0.92, MDC 5.2-10°) (Wollin et al. 2016).

118

119 Pre- and post-match testing was conducted at the home ground of the participants (Manuka Oval,
120 Canberra). Immediate post-match recovery was standardised for all participants and involved
121 ingestion of 250mL of electrolyte drink and water as desired just prior to completion of post-match
122 testing. For the subsequent time periods following match play (26, 50 and 74hours), testing was
123 conducted at the Australian Institute of Sport Physical Therapies Department using the same

124 equipment and set up. All knee flexion isometric strength tests were conducted by a senior
125 physiotherapist (PC) who was familiar with the testing procedures. All flexibility testing was
126 conducted by a senior physiotherapist (SR) also familiar with the testing procedures. Athlete age,
127 height and weight and lever length was collected by a trained research assistant who also recorded
128 knee flexion strength testing results such that both the assessor and participants were blinded to the
129 results. For flexibility testing, only the participants were blinded to the results due to logistical
130 reasons. Participants were allocated a random order of assessment as well as random test order prior
131 to baseline testing and this sequence was maintained for the remainder of the testing time points. The
132 testing procedure was conducted around a single competitive match, during the in-season period.

133

134 All data was assessed for normality using the Shapiro-Wilk test and via visual inspection. All
135 statistical analyses were performed using Stata 13 IC (*StataCorp, USA*). Pilot analyses indicated that
136 an *a priori* estimate of group size indicated at least six participants were required (estimated 73N
137 difference in effect parameters; $\alpha=0.05$; $\beta=0.20$). To assess the relationship of match-play on all the
138 strength and flexibility measurements, a linear mixed-effect model (restricted maximum likelihood
139 [REML] regression) was fitted with time (pre, post, 26-, 50-, 74- hours) as a fixed effect for each
140 physical measurement. A random effect for side (left or right) was fitted within participant to account
141 for within side and participant variances. To avoid errors associated with comparisons of normalised
142 data, raw values were utilised in the mixed model (Dankel, Mouser, Mattocks, 2016). Normalised
143 baseline characteristics were determined for the purposes of comparison with other populations.
144 Statistical significance was determined when the 95% confidence intervals of the fixed effects within
145 the model did not include zero, where zero represents no change from baseline. Clinically meaningful
146 changes for all tests were set *a priori* as KTW (>2cm change), AKE (>10° change), MTT (>10°
147 change) and isometric knee flexion strength (>14% of group baseline, 59.7N, as this is smallest
148 detectable change measurable by the test) (Wollin et al. 2016). These values were determined
149 according to the SEM and MDC of each test (outlined above), whereby any observed change was
150 required to sufficiently exceed both of these measures for it to be considered clinically meaningful.
151 Individual responses are represented in a “profile plot” (“profileplot” command, Stata 13IC) to

152 indicate the individual nature of the response to the competition. The use of raw values, mean change
153 and 95% confidence intervals as well as the plotting of individual responses was based on published
154 recommendations (Dankel et al. 2016).

155

156 **Results**

157 Ten healthy male adult semi-professional AF athletes (mean \pm SD; age, 21.3 ± 2.2 years; height,
158 186.1 ± 6.3 cm; weight, 83.5 ± 8.6 kg) volunteered to participate in this study. Five athletes were
159 midfield positions and five athletes were forwards/backs. The baseline measures for the group across
160 the four tests were (mean \pm SD): knee flexion strength (raw values, right 438 ± 70.6 N, left $414.7 \pm$
161 86.3 N, normalised, right 2.3 ± 0.3 Nmkg⁻¹, left 2.2 ± 0.3 Nmkg⁻¹), KTW (right 12 ± 2.7 cm, left $11.$
162 5 ± 3.3 cm), AKE (right $163.7 \pm 8.5^\circ$, left $166.4 \pm 6.3^\circ$) and MTT (right $14.1 \pm 7.7^\circ$, left $13.1 \pm 8.3^\circ$).

163 The Shapiro-Wilk Test and visual inspections indicated that bilateral isometric knee flexion strength,
164 bilateral KTW and right sided AKE were normally distributed and parametric statistics could be
165 applied. The results of the linear mixed model are presented in Figure 1. Maximal isometric knee
166 flexion strength was significantly reduced compared to baseline pre-match measures at two time
167 periods; post-match (-122.8 N, 95% CI -156.2 to -89.4 , $p=0.000$) and 26 hours post-match (-89.6 N,
168 95% CI -122.9 to -56.2 , $p =0.000$). No significant group changes were noted for the other time
169 periods. KTW was significantly decreased post-match (-1.3 cm, 95% CI -2.01 to -0.54 , $p=0.001$)
170 compared to baseline pre-match measures. KTW was also significantly increased compared to
171 baseline at 50 hours (1.2 cm, 95% CI 0.42 to 1.90 , $p=0.002$) and 74 hours (1.4 cm, 95% CI 0.68 to
172 2.18 , $p=0.000$) post-match. Whilst these results were statistically significant, the values were small
173 and did not exceed clinically meaningful changes. AKE was significantly decreased at all time periods
174 post-match compared with baseline pre-match measures. Changes from baseline ranged from -3.82°
175 (95% CI -6.6 to -1.1 , $p=0.006$) post-game to -4.67° (95% CI -7.4 to -1.9 , $p=0.001$) at 74 hours post-
176 game, and therefore were not clinically meaningful. MTT scores were significantly increased at 50
177 hours (5.63° , 95% CI 2.85 to 8.40 , $p=0.000$) and 74 hours (4.83° , 95% CI 2.02 to 7.65 , $p=0.001$) post-

178 match compared with pre-match measures. These scores were small and did not exceed clinically
179 meaningful changes. For all tests the responses were highly individual and are visually represented
180 across time-periods in Figure 2.

181 **Figure 1** Predictive margins based on mixed model statistics for all outcome measures, with 95%
182 confidence intervals (CIs) representing effect size.

183 *[Insert Figure 1 about here]*

184 Footnote: *statistically significant change from baseline; # clinically meaningful change from baseline.
185 Dashed lines represent clinically meaningful margins from baseline measures. AKE, active knee
186 extension; MTT, modified Thomas test; KTW, knee to wall test; N, Newtons; cm, centimetres.

187 **Figure 2** Profile plot of individual responses to competitive match-play across time points.

188 *[Insert Figure 2 about here]*

189 Footnote: AKE, active knee extension; MTT, modified Thomas test; KTW, knee to wall test; N,
190 newtons; cm, centimetres.

191 **Discussion**

192 A significant reduction in knee flexion strength was reported acutely post-match and at 26 hours post-
193 match compared with baseline pre-match measures. On a group level, knee flexion strength was
194 restored to pre-match levels by 50 hours post-match. Whilst there was also a number of flexibility
195 measures that were significantly different to baseline measures, these numbers were small and did not
196 exceed MDC values for the tests and therefore were not considered to be clinically meaningful as
197 determined by the *a priori* criteria.

198 This study has replicated the findings observed in junior elite soccer athletes following competitive
199 match-play (Wollin et al. 2016) whereby a significant reduction in isometric knee flexion strength was
200 measured immediately and 24 hours post-game. The current study utilised the same knee flexion
201 strength testing protocol and equipment as Wollin et al. (2016) and was able to demonstrate similar

202 reductions in knee flexion strength despite differences in code of football and age group. It has been
203 shown, however that sub-elite AF matches cover greater mean total distances $(13174\text{m})^2$ compared
204 with soccer (10720m for top-class athletes) (Mohr et al. 2003), and therefore it is logical that similar if
205 not greater strength reductions may be evident. Similar post-exercise results have also been
206 reproduced using match-simulation running protocols and testing using isokinetic dynamometry
207 (Greig & Siegler, 2009; Small, McNaughton, Greig, 2010; Robineau, Jouaux, Lacroix, 2012).
208 Advantages of the isometric protocol utilised in the current study as opposed to isokinetic testing are
209 that it is more clinically feasible for sub-elite populations being quicker, lower cost and having
210 minimal set up requirements.

211 The strength reductions observed in this study immediately and at 26 hours following match-play are
212 similar to those observed in delayed onset muscle soreness studies whereby peak torque deficits are
213 most evident at 24-48 hours following intense eccentric exercise (Cheung, Hume & Maxwell, 2003).
214 These deficits are most apparent for eccentric actions and less pronounced for isometric actions
215 (Smith, 1992). Whilst this information regarding the effects of delayed onset muscle soreness has
216 been available for decades, new information that this study provides is the nature of activity
217 investigated and the clinically feasible methods of assessment.

218 At a group level, knee flexion strength had recovered to pre-match levels by 50 hours. This implies
219 that most athletes should regain baseline isometric strength at this time and where this has not
220 returned to baseline levels, secondary prevention strategies such as training load modification or
221 further recovery modalities might be indicated until strength is returned. Given the association
222 between maximal speed sprinting and incidence of hamstring strain injury (Askling, Tengvar, Saartok
223 et al. 2007) as well as the association between large weekly volumes of high speed running and injury
224 (Duhig et al. 2016) it may be pertinent to delay bouts of high speed running within training sessions
225 until isometric strength has returned to baseline levels. Recovery strategies such as cold water
226 immersion which have been shown to reduce deficits in isometric lower limb strength compared with
227 no intervention following exhaustive team sport exercise (Ingram, Dawson, Goodman et al. 2009)
228 could also be considered. This finding that isometric knee flexion strength had recovered to baseline

229 measures within 50 hours following competition is also relevant when considering injury risk and
230 congested competition fixtures. Whilst currently unknown in AF, it has been shown in professional
231 soccer that muscle injury rates are lower when match exposures are a minimum of six days apart
232 (Bengtsson, Ekstrand, Walden et al. 2017). Inability to recover hamstring strength in a timely manner
233 may be especially pertinent given repeated exposures to competition and future research is required to
234 investigate this relationship with regard to hamstring injury.

235 At a group level, the results of this study indicate that AKE was significantly reduced at all time-
236 periods following match play. However, these values were small and therefore not considered
237 clinically meaningful. The AKE test has previously demonstrated prognostic value in track and field
238 athletes with early deficits in range of motion correlated with time to full athletic activities following
239 hamstring strain (Malliaropoulos, Papacostas, Kiristi, 2010). Tertiary prevention is aimed at providing
240 interventions which reduce the complications of the current pathology. These complications may be
241 recurrent injuries, subsequent injuries of other body areas and persisting deficits that impact function
242 (Jacobsson & Timpka, 2015). In this situation, where an athlete is in a tertiary prevention program,
243 monitoring hamstring length using AKE following match-play may be warranted.

244 This study has several strengths. The protocol was time efficient and inexpensive to set-up.
245 Combining the results of this study and previous work (Wollin et al. 2016), the generalisability of the
246 results appears to indicate that isometric strength of the knee flexors is reduced for a period of one to
247 two days after a single game and is not restricted to the elite sporting environment. Additionally, this
248 study was conducted using competitive match-play and not a simulated treadmill protocol that may
249 not necessarily replicate the demands of competition, including motivation to perform repetitive high
250 intensity efforts and sports specific skills such as kicking. Simulated protocols have identified
251 significant reductions as early as halftime (45 minutes) during a match (Greig & Siegler, 2009).
252 Epidemiological evidence suggests that hamstring strains tend to occur in the latter stages of soccer
253 matches and movement demands in AF have been shown to be reduced in the second half of match-
254 play at both the elite and sub-elite level (Brewer et al. 2010). One limitation of this study was,

255 however, the inability to compare external load (metres and running speed) to decrements in strength
256 as Global Positioning System units were unavailable.

257 Future research should investigate the ability of the isometric knee flexion strength test as a secondary
258 prevention program. Currently, this study has been able to show this test to be clinically feasible and
259 sensitive to match-play in Australian Rules football. Conversely, given the large variability across
260 days and the interaction with competition workloads, this test would appear to be inappropriate as a
261 “once off” pre-season screening test and therefore not recommended as a primary prevention tool.
262 Additionally, whilst there is inconsistent evidence regarding persisting deficits of isokinetic strength
263 following hamstring injury (Maniar, Shield, Williams et al. 2016), there is emerging evidence of
264 persisting isometric deficits (Hickey, Hickey, Maniar et al. 2017). If athletes with a history of
265 hamstring strains have persistent deficits in isometric knee flexion strength measures this may then
266 form a component of tertiary prevention. For example, knee flexion strength programs targeted at
267 athletes with a past-history of hamstring strain injury could be implemented to address any identified
268 strength deficits. Future research could also investigate whether similar results on a group level are
269 evident over time as opposed to a single occasion of match-play and whether different teams from
270 different levels of competition respond in the same way. Similarly, given the positional differences in
271 total and high speed distances observed during competition in professional AF athletes (Gray &
272 Jenkins, 2010), the potential effect of this on magnitude of strength decrements could be explored.

273 **Conclusion**

274 Maximal voluntary isometric knee flexion strength is sensitive to the effects of competition in semi-
275 professional AF athletes and remains significantly reduced at 26 hours following match-play. This
276 information highlights its potential as a component of a secondary prevention program. This
277 information may also assist with planning subsequent training sessions following match-play
278 especially those involving large volumes of high speed running. Testing maximal isometric hamstring
279 strength using the methods described in this study is an efficient and relatively low cost option,
280 however due to the variability of strength observed following competition, it is not recommended for

281 use as a single pre-season measure for primary prevention purposes. Of the physical tests investigated,
282 isometric knee flexion strength was the only measure to reach group clinical and statistical differences
283 from baseline.

284 **Conflict of interest statement**

285 None declared.

286 **Ethical Statement**

287 This study was approved by the Australian Institute of Sport Ethics Committee (Approval Number:
288 20160805) and was conducted in accordance with the Helsinki Declaration. Participants provided
289 written informed consent.

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296

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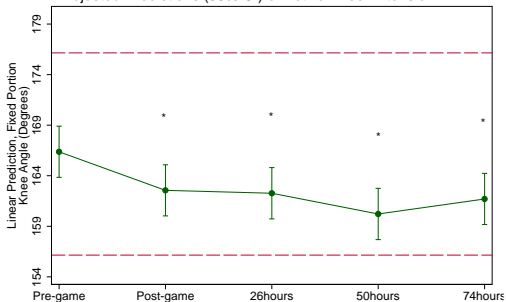
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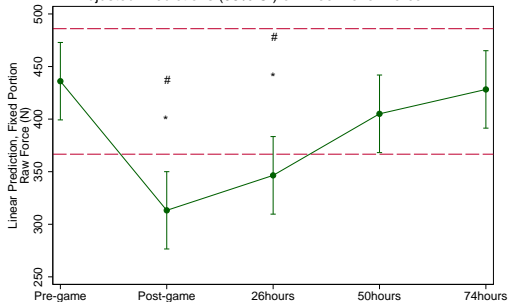
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Results of physical measures across testing periods

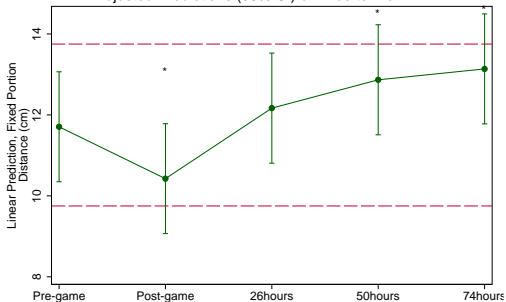
Adjusted Predictions (95% CI) of Active Knee Extension



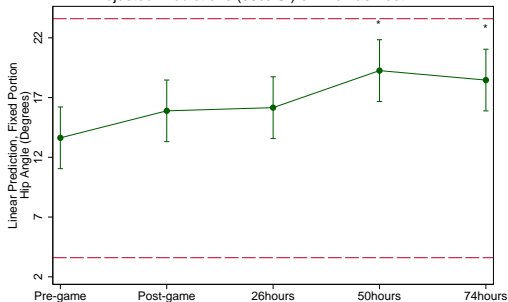
Adjusted Predictions (95% CI) of Knee Flexor Force



Adjusted Predictions (95% CI) of Knee to Wall

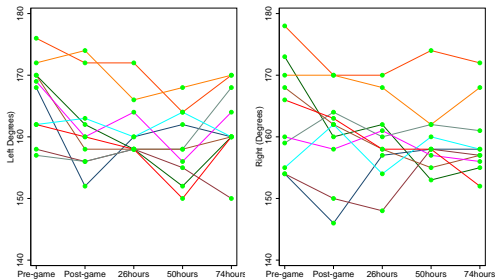


Adjusted Predictions (95% CI) of Thomas Test

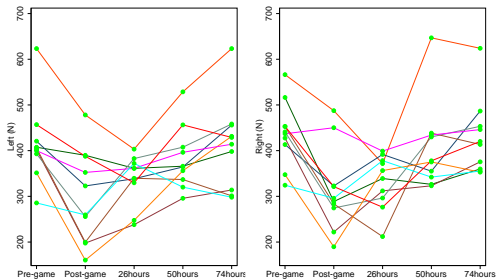


Individual responses of physical measures across testing periods

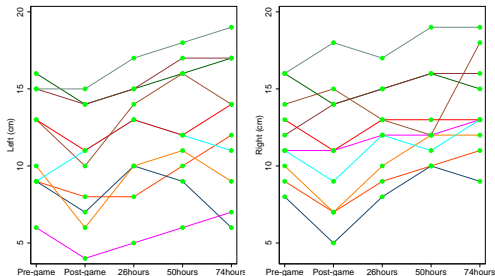
Active Knee Extension



Knee Flexor Force



Knee to Wall



Thomas Test

