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1 **Title of Article:** Relationships between eccentric and concentric knee strength capacities
2 and maximal linear deceleration ability in male academy soccer players

3 **Preferred Running Ahead:** Relationships between knee strength capacities and
4 maximal linear deceleration ability

5

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33 **Relationships between eccentric and concentric knee strength**
34 **capacities and maximal linear deceleration ability in male academy**
35 **soccer players**

36

37 Abstract

38 The purpose of this study was to investigate the relationships between maximal linear
39 deceleration ability, and knee flexor (KF) and extensor (KE) strength. Fourteen male academy
40 soccer players completed a 30 m linear sprint, a maximal linear deceleration test, and eccentric
41 and concentric KF and KE contractions in both dominant (DL) and non-dominant (NDL) legs at
42 slower ($60^{\circ}\cdot\text{s}^{-1}$) and faster ($180^{\circ}\cdot\text{s}^{-1}$) angular velocities on an isokinetic dynamometer (IKD).
43 Maximal linear deceleration ability was evaluated using distance-to-stop (DEC-DTS) and time-
44 to-stop (DEC-TTS), with isokinetic peak torque representing KF and KE strength capacity.
45 Relationships were established using Pearson's correlation coefficients (r) with magnitude-
46 based inferences used to describe the uncertainty in the correlation. Both concentric KE and KF
47 strength at $180^{\circ}\cdot\text{s}^{-1}$ in the NDL had the highest correlations with deceleration ability ($r = -0.76$
48 and $r = -0.78$ respectively). In the DL concentric KE and KF strength at $180^{\circ}\cdot\text{s}^{-1}$ also had *very*
49 *likely* large correlations with deceleration ability ($r = -0.54$ and -0.55 , respectively). All
50 correlations between eccentric KF strength and deceleration ability were *unclear*. At $180^{\circ}\cdot\text{s}^{-1}$,
51 correlations between eccentric KE strength and deceleration ability were also *unclear*, however
52 at $60^{\circ}\cdot\text{s}^{-1}$ both DL ($r = -0.63$ to -0.64) and NDL ($r = -0.54$ to -0.55) had *very likely* large
53 correlations with deceleration ability. These findings provide novel insights into the unilateral
54 KF and KE strength capacities underpinning the ability to decelerate rapidly from high sprint
55 velocities.

56

57 **Key Words:** *braking, isokinetic, unilateral, quadriceps, hamstrings*

58

59

60

61 INTRODUCTION

62 Evolutionary developments in soccer match play have resulted in elite players
63 required to perform more high-intensity actions (1). For instance, recent time motion
64 analysis studies have shown that players could perform on average 16-39 high intensity
65 ($\geq 3\text{m}\cdot\text{s}^{-2}$) accelerations and 43-54 high intensity ($\leq 3\text{m}\cdot\text{s}^{-2}$) decelerations per match,
66 thereby imposing substantial metabolic and mechanical load on players (17,33,37).
67 Whilst an overwhelming amount of research has been devoted to understanding the
68 most optimal training interventions that could be used to enhance maximal acceleration
69 (29,32,34), there is currently little experimental evidence available on how to best
70 develop maximal deceleration capabilities.

71

72 It has previously been suggested that four major physical qualities exert a
73 significant influence on deceleration ability, namely: dynamic balance, eccentric
74 strength, power and reactive strength (22). In studies examining change of direction
75 (COD) performance necessitating the production of large braking forces, it has been
76 shown that high lower limb eccentric strength capabilities increase braking force
77 potential, thereby promoting whole-body deceleration (19,20,24,36). Interestingly, the
78 quadriceps have been suggested to be the 'primary' muscle group regulating sudden
79 deceleration ability (14) due to their role in resisting knee flexion (6) and facilitating the
80 absorption and distribution of eccentric loads at the knee (22). Only one previous
81 study, however, has examined the influence of eccentric KE strength on the ability to
82 decelerate rapidly prior to a COD (20). Importantly, here, players with greater eccentric
83 KE strength decelerated more rapidly during the steps immediately prior to a COD,
84 thereby permitting a faster approach velocity, and a significantly faster COD
85 performance time.

86

87 Eccentric KF strength has also been shown to discriminate between the COD
88 performance of elite players (5). These authors suggested that this might be due to the
89 hamstrings role in mediating the braking forces during sudden COD. Similar findings
90 have been reported by Jones et al. (19,21) although they suggested that increases in
91 eccentric KF strength facilitated the generation of hip extensor torque necessary for
92 maintenance of trunk position, and the dynamic control of knee flexion.

93

94 A potential limitation of these previous studies, however, is that specific knee
95 strength qualities were evaluated during decelerations from relatively low sprinting
96 velocities. For example, during the 505 test (15m approach; 180 degree turn; 5m
97 return), commonly used to examine COD performance, horizontal approach velocities
98 typically range between 3.74 to 4.03m·s⁻¹ (20). Decelerations during match play,
99 however, frequently commence from high (>5.4m·s⁻¹) sprinting velocities (2,25),
100 subsequently imposing greater deceleration demands (40). Although decelerations from
101 high velocity linear sprints are a crucial dimension of match play (3), only one previous
102 study has investigated the knee strength capacities associated with such a maximal
103 linear deceleration task (26). However, the maximal deceleration was performed
104 following a 10m acceleration, and only eccentric KF strength was measured.

105

106 A better understanding of the specific knee strength capacities underpinning
107 deceleration from high sprint velocities could be particularly important for professionals
108 tasked with conditioning populations at heightened risk of injury during rapid
109 decelerations, such as maturing youth soccer players (31). Similarly, a greater
110 understanding of both the KF and KE strength capacities underpinning deceleration

111 from high sprint velocities may serve to better inform the physical preparation of soccer
112 players. Accordingly, the aim of this study was to examine the isokinetic eccentric and
113 concentric KF and KE strength capacities of male academy soccer players, and to
114 determine their relationships to deceleration ability from high velocity sprints.

115

116 **METHODS**

117 **Experimental Approach to the Problem**

118

119 This study incorporated a descriptive within-subject cross-sectional design to
120 investigate the relationships between eccentric and concentric KF and KE strength in
121 both DL and NDL with maximal linear deceleration ability. To diminish the effects of
122 residual fatigue and circadian variation (30) test procedures took place across three
123 testing sessions, during the player's regular training hours (between 10.00 and 13.00),
124 and were separated by at least 48 hours. The first session included assessment of all
125 anthropometric measurements and IKD strength testing. Field based testing sessions
126 took place on an artificial turf surface and commenced with a 10-minute standardized
127 dynamic warm-up (e.g. lunges, squats, skipping) and three progressive 20 m
128 accelerations with a submaximal linear deceleration. In session two, players completed
129 a 30m linear sprint. In session three, maximal linear deceleration ability was assessed.
130 All players were accustomed to this maximal linear deceleration protocol during regular
131 field based training sessions prior to testing.

132

133 **Subjects**

134 Fourteen male youth soccer players (age: 16.8 ± 0.9 years, height: 175.1 ± 8.6 cm, body
135 mass: 68.5 ± 7.8 kg, body fat: $9.5 \pm 4.3\%$) from an English professional League Two

136 soccer academy participated in this study. All players had completed a period of pre-
137 season training, 3 months of the competitive season and were free from any lower limb
138 injury during this period. During the competition phase all players trained at the
139 academy 2-3 times per week, in addition to 1 competitive fixture. The study was
140 submitted and approved by the local University Institutional Ethics Committee. Prior to
141 taking part in the study subjects were informed of the benefits and risks, with informed
142 assent and parental consent then subsequently obtained.

143

144 **Procedures**

145 *Anthropometry.* Standing height was measured to the nearest 0.1mm using a stadiometer
146 (Seca 217, Hamburg, Germany), and body mass to the nearest 0.1kg using electronic
147 weighing scales (Seca, Hamburg, Germany). Body fat percentage was estimated
148 through air displacement plethysmography using BODPOD (Life Measurements
149 Instruments, Concord, CA, USA).

150

151 *Isokinetic Dynamometer Strength Testing.* Procedures followed those of previous
152 studies measuring IKD strength in soccer players (9,10). Testing was preceded by a
153 standardised 5-minute warm-up of light cycling (Wattbike, Wattbike Ltd, Nottingham,
154 UK) interspersed with two short sprints (10 s each) at 3 and 4 minutes. Participants
155 were seated on the IKD (Cybex Norm, Lumex, Ronkokoma, NY, USA) with a reclined
156 trunk angle of 15° from the vertical similar to the previous studies. Segmental
157 stabilization was achieved with straps across the shoulders, thigh and tibia (2 cm above
158 the lateral malleoli). Alignment of knee joint axis with the dynamometer axis of rotation
159 was obtained under active (sub-maximal isometric at mid-range of motion) conditions
160 to help minimize axis misalignment. Range of motion was set from full knee extension

161 (0°) to 90°. Both legs were tested during concentric and eccentric contraction modes
162 during KF and KE at slower ($60^{\circ}\cdot\text{s}^{-1}$) and faster ($180^{\circ}\cdot\text{s}^{-1}$) angular velocities, with the
163 DL defined as the kicking leg. Prior to maximal testing, participants performed an IKD
164 specific warm up consisting of 5 sub-maximal concentric and eccentric repetitions in
165 both legs at $60^{\circ}\cdot\text{s}^{-1}$. Maximal testing was performed in random order, with 5 maximal
166 efforts allowed for each trial. A 2-minute rest period was standardized between each
167 trial. All participants were given consistent and standardized verbal encouragement (i.e.
168 tone and pitch) in order to increase motivation and level of muscle activation. The
169 highest peak torque (N·m) value observed across the 5 maximal repetitions during the
170 isokinetic phase was used for final analysis, and was representative of strength capacity
171 during each test condition.

172

173 *Linear Sprint Test.* Sprints times were recorded over a 30 m distance (with 20 m split
174 time) using timing gates (Witty, Microgate, Bolzano, Italy) set to a height of 0.8m (8).
175 Times were recorded to the nearest 0.01s. Each sprint commenced from a standing static
176 start position with the front foot positioned 30 cm behind the timing gate to prevent a
177 false trigger. Participants were instructed to initiate their own start with no backward
178 step or ‘rocking motion’ and to sprint as fast as possible. Each participant was allowed 2
179 trials with at least 60 seconds recovery between with the best 20 m split used as a
180 ‘criterion’ time in the maximal linear deceleration test.

181

182 *Maximal Linear Deceleration Ability Test.* Maximal linear deceleration ability was
183 assessed using an acceleration-deceleration ability (ADA) test. Prior to commencement
184 of the test, a high-contrast colour marker was positioned on the greater trochanter of
185 each participant. In order to reduce movement artifact of the marker, the marker was

186 positioned on top of black taping that was securely fitted around the shorts of the
187 participant. Participants were instructed to use the same start protocol used for the linear
188 sprint test and sprint maximally over 20 m before performing a maximal linear
189 deceleration. Immediately following the deceleration, players backpedalled to the 20m
190 line to create a clear ‘stop’ event and to signify the end of the deceleration phase (figure
191 1). Any 20m time that was 5% greater than the best 20 m split time achieved during the
192 linear sprint test was considered as an unsuccessful trial, and the player was asked to
193 repeat the test following at least a 3-minute recovery period. Each player’s maximal
194 linear deceleration ability was recorded with a digital camera (Panasonic HDC-HS900,
195 Japan, sampling at 50 Hz) positioned 10 m perpendicular to the plane of motion.
196 Maximal linear deceleration ability was evaluated using distance to stop (DTS) and time
197 to stop (TTS), calculated using DartfishPro Suite digitisation software (Dartfish,
198 Fribourg, CH). Two independent observers determined the start of the deceleration
199 phase defined as the frame in which the hip marker passed the 20 m marker, and the
200 first posterior displacement of the hip marker, preceding the backpedal, which defined
201 the end of the deceleration phase. Pilot testing demonstrated that the between trial
202 coefficient of variation (CV) for DEC-DTS and DEC-TTS was 1.5 and 2.3%
203 respectively.

204

205 < INSERT FIGURE 1 ABOUT HERE >

206

207 **Statistical Analysis**

208 Mean \pm standard deviation (SD) and 90% confidence intervals (90% CI’s) were
209 calculated for all dependent and independent variables. Prior to analyses, assumption of
210 normality for all variables was confirmed using the Shapiro-Wilk test. Pearson’s

211 product-moment correlation coefficients (r) were calculated to examine the relationship
212 between deceleration variables (DEC-DTS and DEC-TTS) and the IKD strength
213 measures using SPSS for Mac (version 20.0; SPSS, Chicago, IL, USA). Equality of
214 variance was checked with Levene's test. 90% CI's for all correlations were constructed
215 in accordance with Hopkins (16). If the 90% CI overlapped small positive or negative
216 values the correlation was deemed unclear and removed from the analysis. The
217 magnitude of the correlation co-efficient was interpreted using criteria provided by
218 Hopkins (15): small (0.11 – 0.29), moderate (0.30-0.49), large(0.50-0.69), very
219 large(0.7-0.89) and almost perfect(≥ 0.90). The coefficient of determination (r^2) was
220 used to illustrate the shared variance of correlations and presented as a % ($r^2 \times 100$).
221 Magnitude based inferences were derived from r values (16) and used to describe the
222 uncertainty in effect of the correlation: *very unlikely* (<0.49%), *unlikely*(5–24.9%),
223 *possibly* (25-74.9%), *likely* (75–94.9%), *very likely* (95–99.4%), *most likely* (>99.5%).

224

225 **RESULTS**

226 Sprint testing and maximal linear deceleration ability scores are shown in table 1. The
227 eccentric and concentric KF and KE strength values, for both DL and ND, are shown
228 in table 2.

229

230 < INSERT TABLE 1 ABOUT HERE >

231 < INSERT TABLE 2 ABOUT HERE >

232

233 All correlations between the IKD strength measures and deceleration ability are shown
234 in table 3 (DEC-TTS) and table 4 (DEC-DTS).

235

236 < INSERT TABLE 3ABOUT HERE >

237 < INSERT TABLE 4ABOUT HERE >

238

239 *Relationships between eccentric strength and deceleration ability*

240 All correlations between eccentric KF and deceleration ability were *unclear*. At $180^{\circ}\cdot\text{s}^{-1}$

241 correlations between eccentric KE strength and deceleration ability were also *unclear*.

242 However, at $60^{\circ}\cdot\text{s}^{-1}$ both DL and NLD had *very likely* large correlations with DEC-DTS

243 ($r = -0.54$ and -0.55 , respectively) and DEC-TTS ($r = -0.63$ and -0.64 , respectively). For

244 the DL eccentric KE strength at $60^{\circ}\cdot\text{s}^{-1}$ provided the highest correlation ($r = -0.63$) with

245 DEC-TTS.

246

247 *Relationships between concentric strength and deceleration ability*

248 Interestingly, the highest correlations for both DEC-DTS and DEC-TTS was observed

249 in concentric KF ($r = -0.78$) and KE ($r = -0.76$) strength respectively at $180^{\circ}\cdot\text{s}^{-1}$ in the

250 NDL, explaining between 57 to 60% of the shared variance. In the DL concentric KE

251 strength at $180^{\circ}\cdot\text{s}^{-1}$ also had *very likely* large correlations to both DEC-DTS ($r = -0.64$)

252 and DEC-TTS ($r = -0.54$) although the shared variance was less (29-30%).

253

254 **DISCUSSION**

255 This is the first study to measure the KF and KE eccentric and concentric

256 strength capacities in both DL and NDL, and examine their relationship with the ability

257 to decelerate in less distance and time from high sprinting velocities. The main findings

258 of our study was that (1) concentric KF and KE strength in the NDL measured at faster

259 angular velocities had the largest correlations with both DEC-DTS and DEC-TTS, (2) in

260 the DL, concentric KE and KF measured at faster angular velocities also had very likely

261 large correlations with deceleration ability, and (3) very likely large correlations were
262 found between eccentric KE strength in both DL and NDL at $60^{\circ}\cdot\text{s}^{-1}$ and deceleration
263 ability. Interestingly, all correlations between eccentric KF and deceleration ability were
264 *unclear*.

265

266 Most previous studies examining the importance of lower limb strength on
267 deceleration ability have used COD tasks, with more severe COD angles or faster
268 approach velocities resulting in increased deceleration demands (i.e. a greater need to
269 reduce forward momentum). There is clear consensus amongst these studies that higher
270 levels of lower limb eccentric strength facilitates superior braking capacity
271 (19,20,24,36). Our findings add to this research by highlighting that it is specifically
272 higher levels of KE eccentric strength at slower angular velocities that is especially
273 required in both the DL and NDL. Both the DL and NDL had *very likely* large
274 correlations with DEC-DTS and DEC-TTS. These findings agree with Jones et al. (21),
275 who established that players with greater eccentric KE strength were able to produce
276 significantly greater deceleration, thereby suggesting these players could maintain a
277 higher entry velocity into the COD event.

278

279 Taken together these findings demonstrate the importance of unilateral eccentric
280 KE strength in promoting deceleration ability. Accordingly, strength and conditioning
281 practitioners should seek to design and select exercises challenging the KE musculature
282 in slow tempo eccentric contractions. Examples of potentially useful exercises include
283 the use of accentuated eccentric exercises (4) using commercially-available specialized
284 equipment (39). Future research, however, is required to establish the influence of
285 accentuated eccentric training on deceleration ability.

286

287 Currently, within the literature, there remains a lack of certainty relating to the
288 influence of eccentric KF strength on deceleration performance. Surprisingly, all
289 relationships in our study between this capacity and deceleration ability were *unclear*.
290 In studies examining global COD performance (i.e. total time taken to perform the COD
291 task), eccentric KF strength was significantly correlated to COD performance (19,24),
292 and was capable of discriminating between elite and sub-elite players (5). The
293 subsequent speculation was that eccentric KF strength could play multiple roles during
294 deceleration, such as: mediating braking forces (5); supplementing the hip extensor
295 torque necessary to maintain trunk position (19); controlling KF during pivots and
296 turns, and contributing to the absorption of forces (24). In agreement with our findings,
297 when the deceleration phase prior to a COD has been investigated, eccentric KF
298 strength has been shown to have a less significant role in the production of braking
299 forces required to decelerate rapidly (20). In this study players with greater overall
300 eccentric strength (KF plus KE) had higher hip extensor moment during the
301 deceleration steps, thereby implying that eccentric KF strength plays an important role
302 in controlling trunk flexion, and providing necessary co-contraction to assist with knee
303 stability.

304

305 Only one previous study (26) has examined the relationship between eccentric
306 KF strength and the capacity to decelerate linearly in less distance. Contrary to our
307 findings this study found that eccentric KF strength at slower angular velocities was the
308 best predictor (32%) of DEC-DTS. In the study by Naylor & Greig (26) the deceleration
309 was un-anticipated. This could place greater reliance on eccentric KF strength in order
310 to control trunk and pelvic positions, and to obtain higher and quicker levels of knee

311 joint stabilization (35). Another possible explanation is that players in our study
312 performed the deceleration following a 20 m sprint compared to a 10 m sprint in the
313 protocol used by Naylor and Greig (26). Therefore, the players approach velocity and
314 momentum were likely higher in our study making the deceleration demands
315 considerably more challenging. In fact the average approach velocity prior to
316 deceleration was $6.3 \text{ m}\cdot\text{s}^{-1}$, which is higher than previous studies ($3.6 - 5.8 \text{ m}\cdot\text{s}^{-1}$)
317 examining the deceleration phase prior to a COD (13,21,27).

318

319 As a high number of decelerations during match play are executed from high (>
320 $5.14 \text{ m}\cdot\text{s}^{-1}$) sprinting velocities (25), the specific strength capacities required to
321 decelerate from high velocities is a critical consideration when devising physical
322 preparation protocols for soccer players. As approach velocities increase, larger braking
323 forces must be applied. Such large forces are typically attained by positioning the
324 centre of mass posteriorly to the braking foot (13), a position imposing substantial load
325 on the quadriceps (6). Further research is required to investigate the role of different KF
326 contraction types on deceleration performance, during planned and un-anticipated
327 conditions. The authors are aware of no research that has, for example, investigated the
328 role of isometric KF strength on deceleration ability.

329

330 Another important finding identified from the correlation analysis was
331 concentric KE and KF strength, at faster angular velocities, in the NDL, had *almost*
332 *certainly* very large relationships with DEC-TTS and DEC-DTS. Significant increases
333 in concentric KE strength at faster angular velocities ($240^\circ\cdot\text{s}^{-1}$) of the NDL have been
334 found following a 5 week period of speed and agility training with an enforced
335 deceleration (23). To our knowledge this is currently the only study to date that has

336 specifically examined the effect of field-based, linear deceleration training on changes
337 in unilateral KE and KF eccentric and concentric strength. While concentric strength is
338 most frequently associated with acceleration abilities, these findings suggest that
339 superior concentric strength —particularly at faster angular velocities— provides a
340 substantial contribution to the capacity to decelerate rapidly in less time and distance.

341

342 Concentric contractions have been shown to be superior to isometric and
343 eccentric contractions in their ability to generate force rapidly due to more effective
344 neuromuscular activation properties (38). Our study found that the largest correlations
345 with concentric strength in the DL and deceleration ability were also at faster angular
346 velocities, in both the KE and KF. This further supports the importance of developing
347 explosive concentric KE and KF strength in facilitating the complex inter-limb co-
348 ordination patterns required to decelerate rapidly. In order to specifically target the
349 development of faster knee joint angular velocities these findings illustrate the
350 importance of including both field based deceleration co-ordination training, together
351 with gym based resistance training approaches, within conditioning programs. For
352 example, velocity based resistance training (VBT) designed to maximize the amount of
353 repetitions performed with high movement velocity (low % velocity loss) has been
354 shown to result in enhanced neuromuscular performance, stimulating improvements in
355 fundamental actions like deceleration in soccer players (28).

356

357 A potential limitation of our study is that the players could pre-plan their
358 deceleration strategy. In match play it is likely most decelerations are performed in
359 unanticipated situations, thereby posing more sophisticated challenges to motor control.
360 It would be useful to understand the physical capacities required to decelerate

361 maximally under reactive unanticipated conditions. Furthermore, IKD strength
362 assessment could be perceived to be a less ‘functional’ assessment. However, we
363 suggest that IKD strength assessment poses similar load characteristics to those
364 experienced during a maximal linear deceleration. For instance during eccentric
365 quadriceps strength assessment a postero-anterior load vector is created that is similar to
366 that seen during the early ground contact phase of deceleration. The force vector
367 application could have an important role in enhancing the specific strength qualities
368 required for deceleration (12). Finally, future studies should consider additional IKD
369 metrics, such as angle specific torque, which would reveal further insight into the
370 specific joint angular strength qualities required for deceleration (11).

371

372 In summary, this is the first study to measure the KF and KE eccentric and
373 concentric strength capacities in both DL and NDL, and to examine their relationships
374 with deceleration ability from high sprinting velocities. Notably, a high unilateral
375 eccentric KE strength at a slower angular velocity was the only eccentric strength
376 quality related to both DEC-DTS and DEC-TTS. Interestingly, concentric KE and KF
377 strength in the NDL, at higher angular velocities, demonstrated the greatest influence on
378 deceleration ability. In the DL concentric KE at higher angular velocities also had likely
379 large correlations with both DEC-DTS and DEC-TTS. Although the correlations
380 reported in this study cannot assume causality, these findings provide new, potentially
381 useful, information to coaches, sport science and medical practitioners concerned with
382 the preparation of players for the frequent high intensity decelerations implicit in soccer
383 match play.

384

385

386 PRACTICAL APPLICATIONS

387

388 Players perform frequent decelerations from high sprinting velocities during
389 match play. The maximal linear deceleration test used in this study provides a practical
390 means to measure a player's maximal deceleration capabilities from high sprinting
391 velocities—a measure which is difficult to obtain from traditional COD test protocols.
392 To enhance a player's deceleration ability from high sprinting velocities, specific
393 attention could be needed to developing eccentric strength in the KE. For example,
394 eccentric overload that can be safely and effectively achieved using flywheels or other
395 eccentric devices (39) could be used as an acute and/or chronic training intervention to
396 enhance kinetics (e.g. braking forces) and also reduce the risk of tissue damage
397 associated with decelerating (18). Conditioning exercises should also transfer to better
398 deceleration performance through consideration to the force vector application (i.e.
399 postero-anterior braking forces). For example, horizontal braking forces can be
400 systematically overloaded using a cable pulley during a unilateral hop and stick exercise
401 (7).

402

403 The present study also highlights the importance of high velocity concentric
404 strength for enhancing maximal deceleration performance. Consideration to training
405 approaches that facilitate generation and maintenance of high knee joint extension and
406 flexion velocities may promote superior muscle contractile properties required for quick
407 and accurate positioning of limbs when decelerating. To achieve this coaches might
408 consider using velocity based training devices to monitor and maintain movement
409 velocity within specific thresholds during an exercise. This could promote favorable

410 adaptations such as maintenance of type II muscle fibres that are critical for rapid limb
411 movements and force production when decelerating rapidly (28).

412 We hypothesize, in agreement with others (7), that the ability to perform a
413 maximal linear deceleration could be a critical component of COD performance.
414 Secondly, from a perspective of injury prevention, players with greater strength
415 capacities important for decelerating should better attenuate high impacts, thereby
416 resulting in lower levels of mechanical stress and tissue damage.

417

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FIGURE CAPTIONS

Figure 1. Acceleration-deceleration ability (ADA) test layout used to assess players maximal linear deceleration ability.

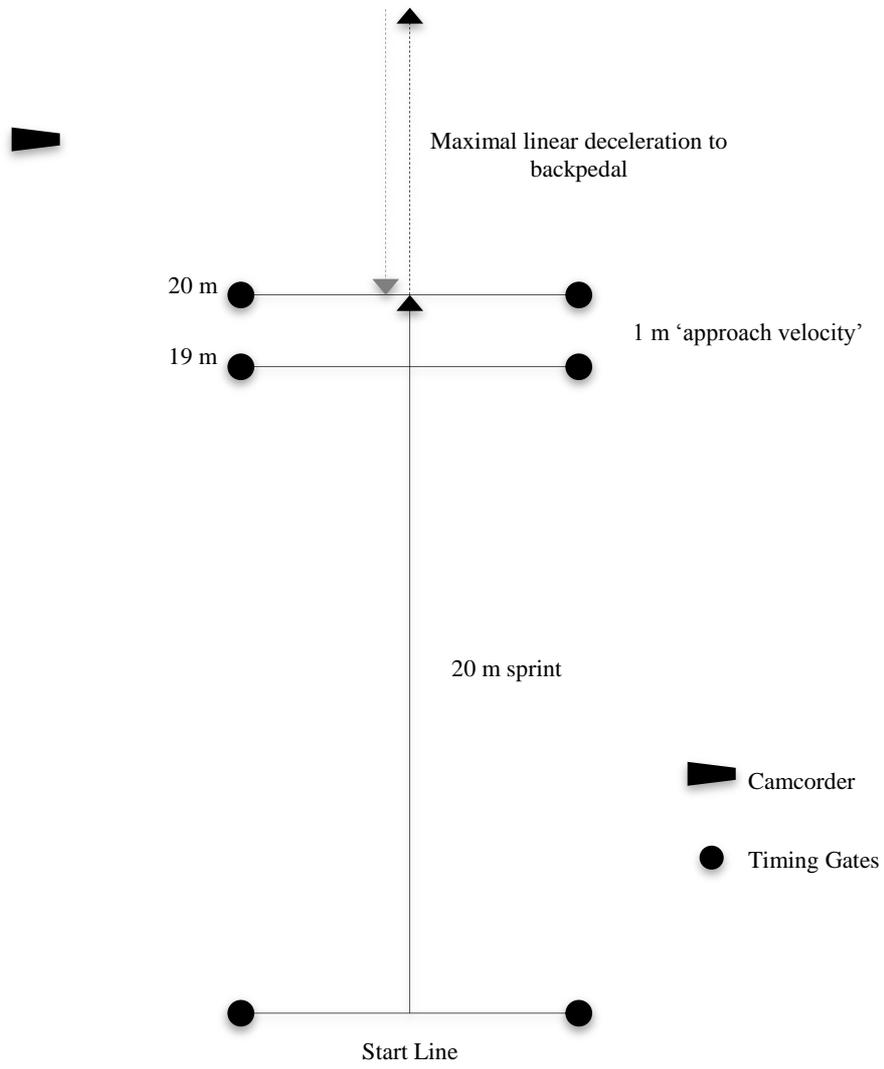


Table 1. Sprint and maximal linear deceleration performance scores

Variables	Mean \pm SD	90% CI
Sprint		
20 m (s)*	3.12 \pm 0.12	3.06 – 3.18
30 m (s)	4.26 \pm 0.12	4.20 – 4.32
Deceleration		
Approach Velocity (m·s ⁻¹)	6.31 \pm 0.48	6.08 – 6.53
DEC-DTS (m)	3.7 \pm 0.52	3.45 – 3.95
DEC-TTS (s)	1.03 \pm 0.15	0.96 – 1.11

Abbreviations: SD = standard deviation; CI = confidence interval; DEC-DTS = deceleration distance to stop; DEC-TTS = deceleration time to stop; m = meters; s = seconds.

*Each players best 20 m split time used as the ‘criterion’ time for the maximal linear deceleration test.

Table 2. Isokinetic dynamometer eccentric and concentric peak torque (N·m) capacities of the knee extensor and knee flexor muscles in dominant (DL) and non-dominant legs (NDL) measured at slower ($60^{\circ}\cdot\text{s}^{-1}$) and faster ($180^{\circ}\cdot\text{s}^{-1}$) angular velocities

Angular velocity	IKD strength capacities	DL (mean \pm SD)	90% CI	NDL (mean \pm SD)	90% CI
$60^{\circ}\cdot\text{s}^{-1}$	ConKE	193.71 \pm 32.24	178.45 – 208.98	189.86 \pm 25.77	177.66 – 202.06
	ConKF	101.71 \pm 18.75	92.84 – 110.59	100.36 \pm 17.58	92.04 – 108.68
	EccKE	223.14 \pm 40.79	203.84 – 242.45	214.79 \pm 53.39	189.51 – 240.06
	EccKF	124.71 \pm 28.49	111.23 – 138.20	121.36 \pm 23.09	110.43 – 132.29
$180^{\circ}\cdot\text{s}^{-1}$	ConKE	133.07 \pm 29.61	119.06 – 147.09	131.29 \pm 25.92	119.02 – 143.55
	ConKF	74.00 \pm 18.75	92.84 – 110.59	72.79 \pm 17.37	64.56 – 81.00
	EccKE	193.86 \pm 41.32	174.30 – 213.42	189.21 \pm 33.21	173.50 – 204.93
	EccKF	119.86 \pm 32.78	104.34 – 135.37	111.86 \pm 28.85	98.20 – 125.51

Abbreviations: N·m = Newton meters; SD = standard deviation; CI = confidence interval; Ecc = eccentric; Con = concentric; KE = knee extensor; KF = knee flexor

Table 3. Relationships and qualitative inference between isokinetic strength variables and deceleration time to stop (DEC-TTS).

IKD strength capacity	Correlation coefficient (90% CI)	Coefficient of determination % (90% CI)	Magnitude of correlation	Likelihood correlation is harmful/trivial/beneficial	Qualitative inference ^a
NDL					
ConKE ₁₈₀	-0.76 (-0.46 to -0.90)	57 (21-81)	Very large	0/0/100	<i>Almost certain</i>
EccKE ₆₀	-0.64 (-0.26 to -0.85)	41 (7-72)	Large	0/1/99	<i>Very Likely</i>
ConKF ₁₈₀	-0.61 (-0.21 to -0.84)	37 (4-71)	Large	0/2/98	<i>Very Likely</i>
ConKF ₆₀	-0.55 (-0.12 to -0.81)	30 (1-66)	Large	1/3/96	<i>Very Likely</i>
DL					
EccKE ₆₀	-0.63 (-0.26 to -0.85)	40 (6-72)	Large	0/2/98	<i>Very Likely</i>
ConKE ₁₈₀	-0.54 (-0.11 to -0.80)	29 (1-64)	Large	1/4/95	<i>Very Likely</i>

^a *Uncertainty of the correlation:* Likely = 75–95% (likelihood of the true correlation being....); Very likely = 95–99%; Almost certain = >99%.

IKD strength correlations deemed unclear (chances of correlation being both >5% harmful and beneficial) = NDL EccKF₆₀; NDL EccKE₁₈₀; NDL ConKE₆₀; DL EccKF₆₀; DL EccKF₁₈₀; DL ConKE₆₀; DL ConKF₆₀; DL ConKF₁₈₀

Abbreviations: IKD = Isokinetic dynamometer; CI = confidence interval; NDL = non-dominant leg; DL = dominant leg; Ecc = eccentric; Con = concentric; KE = knee extensor; KF = knee flexor; 60 = 60°·s⁻¹; 180 = 180°·s⁻¹.

Table 4. Relationships and qualitative inference between isokinetic strength variables and deceleration distance to stop (DEC-DTS).

IKD strength capacity	Correlation coefficient (90% CI)	Coefficient of determination % (90% CI)	Magnitude of correlation	Likelihood correlation is harmful/trivial/beneficial	Qualitative Inference ^a
NDL					
ConKF ₁₈₀	-0.78 (-0.49 to -0.91)	60 (24-83)	Very large	0/0/100	<i>Almost certain</i>
ConKF ₆₀	-0.7 (-0.36 to -0.88)	49 (13-77)	Very large	0/1/99	<i>Almost certain</i>
ConKE ₁₈₀	-0.64 (-0.26 to -0.85)	41 (7-72)	Large	0/1/99	<i>Very likely</i>
EccKE ₆₀	-0.55 (-0.12 to -0.80)	30 (1-66)	Large	1/3/96	<i>Very likely</i>
DL					
ConKE ₁₈₀	-0.55 (-0.12 to -0.81)	30 (1-66)	Large	1/3/96	<i>Very likely</i>
EccKE ₆₀	-0.54 (-0.11 to -0.80)	29 (1-64)	Large	1/4/96	<i>Very likely</i>
ConKF ₁₈₀	-0.54 (-0.11 to -0.80)	29 (1-64)	Large	1/4/96	<i>Very likely</i>

^a *Uncertainty of the correlation:* Likely = 75–95% (likelihood of the true correlation being....); Very likely = 95–99%; Almost certain = >99%.

IKD strength correlations deemed unclear (Chances of correlation being both > 5% harmful and beneficial) = NDL EccKF₆₀; NDL EccKE₁₈₀; NDL ConKE₆₀; DL EccKF₆₀; DL EccKF₁₈₀; DL ConKE₆₀; DL ConKF₆₀.

Abbreviations: IKD = Isokinetic dynamometer; CI = confidence interval; NDL = non-dominant leg; DL = dominant leg; Ecc = eccentric; Con = concentric; KE = knee extensor; KF = knee flexor; 60 = 60°·s⁻¹; 180 = 180°·s⁻¹.