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

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

***Authors and Institutions:***

Damian J Harper[1,2],

Alastair R Jordan[1],

John Kiely[2].

[1] *School of Sport, York St John University, York, UK.*

[2]*Institute of Coaching and Performance, School of Sport and Wellbeing, University of Central Lancashire, Preston, UK.*

***Contact Details for Corresponding Author:***

***Name:*** Damian Harper

***Mail Address:*** School of Sport, York St John University, Lord Mayor's Walk, York, North Yorkshire, YO31 7EX, UK

***Telephone Number:*** 01904 876438

***Email Address:*** d.harper@yorksj.ac.uk

***Twitter:*** @DHMov

**Acknowledgements**: The authors thank all of the players and coaches at the club for their participation and support during this study. No external funding was received for this study and the authors have no conflict of interest to disclose.

**Abstract word count:** 238

**Text only word Count:** 3718

# Relationships between eccentric and concentric knee strength capacities and maximal linear deceleration ability in male academy soccer players

Abstract

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

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

## INTRODUCTION

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

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

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

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

A better understanding of the specific knee strength capacities underpinning deceleration from high sprint velocities could be particularly important for professionals tasked with conditioning populations at heightened risk of injury during rapid decelerations, such as maturing youth soccer players (31). Similarly, a greater understanding of both the KF and KE strength capacities underpinning deceleration from high sprint velocities may serve to better inform the physical preparation of soccer players. Accordingly, the aim of this study was to examine the isokinetic eccentric and concentric KF and KE strength capacities of male academy soccer players, and to determine their relationships to deceleration ability from high velocity sprints.

## METHODS

### Experimental Approach to the Problem

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

### Subjects

Fourteen male youth soccer players (age: 16.8 $\pm$ 0.9 years, height: 175.1$\pm$ 8.6 cm, body mass: 68.5 $\pm$ 7.8 kg, body fat: 9.5 $\pm$ 4.3%) from an English professional League Two soccer academy participated in this study. All players had completed a period of pre-season training, 3 months of the competitive season and were free from any lower limb injury during this period. During the competition phase all players trained at the academy 2-3 times per week, in addition to 1 competitive fixture. The study was submitted and approved by the local University Institutional Ethics Committee. Prior to taking part in the study subjects were informed of the benefits and risks, with informed assent and parental consent then subsequently obtained.

**Procedures**

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

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

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

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

*Maximal Linear Deceleration Ability Test.* Maximal linear deceleration ability was assessed using an acceleration-deceleration ability (ADA) test. Prior to commencement of the test, a high-contrast colour marker was positioned on the greater trochanter of each participant. In order to reduce movement artifact of the marker, the marker was positioned on top of black taping that was securely fitted around the shorts of the participant. Participants were instructed to use the same start protocol used for the linear sprint test and sprint maximally over 20 m before performing a maximal linear deceleration. Immediately following the deceleration, players backpedalled to the 20m line to create a clear ‘stop’ event and to signify the end of the deceleration phase (figure 1). Any 20m time that was 5% greater than the best 20 m split time achieved during the linear sprint test was considered as an unsuccessful trial, and the player was asked to repeat the test following at least a 3-minute recovery period. Each player’s maximal linear deceleration ability was recorded with a digital camera (Panasonic HDC-HS900, Japan, sampling at 50 Hz) positioned 10 m perpendicular to the plane of motion. Maximal linear deceleration ability was evaluated using distance to stop (DTS) and time to stop (TTS), calculated using DartfishPro Suite digitisation software (Dartfish, Fribourg, CH). Two independent observers determined the start of the deceleration phase defined as the frame in which the hip marker passed the 20 m marker, and the first posterior displacement of the hip marker, preceding the backpedal, which defined the end of the deceleration phase. Pilot testing demonstrated that the between trial coefficient of variation (CV) for DEC-DTS and DEC-TTS was 1.5 and 2.3% respectively.

< INSERT FIGURE 1 ABOUT HERE >

**Statistical Analysis**

Mean ±standard deviation (SD) and 90% confidence intervals (90% CI’s) were calculated for all dependent and independent variables. Prior to analyses, assumption of normality for all variables was confirmed using the Shapiro-Wilk test. Pearson’s product-moment correlation coefficients (*r*) were calculated to examine the relationship between deceleration variables (DEC-DTS and DEC-TTS) and the IKD strength measures using SPSS for Mac (version 20.0; SPSS, Chicago, IL, USA). Equality of variance was checked with Levene's test. 90% CI's for all correlations were constructed in accordance with Hopkins (16). If the 90% CI overlapped small positive or negative values the correlation was deemed unclear and removed from the analysis. The magnitude of the correlation co-efficient was interpreted using criteria provided by Hopkins (15): small (0.11 – 0.29), moderate (0.30-0.49), large(0.50-0.69), very large(0.7-0.89) and almost perfect($\geq$ 0.90). The coefficient of determination ($r^2$) was used to illustrate the shared variance of correlations and presented as a % ($r^2$ x 100). Magnitude based inferences were derived from *r* values (16) and used to describe the uncertainty in effect of the correlation: *very unlikely* (<0.49%), *unlikely*(5–24.9%), *possibly* (25-74.9%), *likely* (75–94.9%), *very likely* (95–99.4%), *most likely* (>99.5%).

## RESULTS

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

< INSERT TABLE 1 ABOUT HERE >

< INSERT TABLE 2 ABOUT HERE >

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

< INSERT TABLE 3ABOUT HERE >

< INSERT TABLE 4ABOUT HERE >

*Relationships between eccentric strength and deceleration ability*

All correlations between eccentric KF and deceleration ability were *unclear*. At $180^{\circ}\cdot s^{-1}$ correlations between eccentric KE strength and deceleration ability were also *unclear*. However, at $60^{\circ}\cdot s^{-1}$ both DL and NLD had *very likely* large correlations with DEC-DTS (*r* = -0.54 and -0.55, respectively) and DEC-TTS (*r* = -0.63 and -0.64, respectively). For the DL eccentric KE strength at $60^{\circ}\cdot s^{-1}$ provided the highest correlation (*r* = -0.63) with DEC-TTS.

*Relationships between concentric strength and deceleration ability*

Interestingly, the highest correlations for both DEC-DTS and DEC-TTS was observed in concentric KF (*r* = -0.78) and KE (*r* = -0.76) strength respectively at $180^{\circ}\cdot s^{-1}$ in the NDL, explaining between 57 to 60% of the shared variance. In the DL concentric KE strength at $180^{\circ}\cdot s^{-1}$ also had *very likely* large correlations to both DEC-DTS (*r* = -0.64) and DEC-TTS (*r* = - 0.54) although the shared variance was less (29-30%).

**DISCUSSION**

This is the first study to measure the KF and KE eccentric and concentric strength capacities in both DL and NDL, and examine their relationship with the ability to decelerate in less distance and time from high sprinting velocities. The main findings of our study was that (1) concentric KF and KE strength in the NDL measured at faster angular velocities had the largest correlations with both DEC-DTS and DEC-TTS, (2) in the DL, concentric KE and KF measured at faster angular velocities also had very likely large correlations with deceleration ability, and (3) very likely large correlations were found between eccentric KE strength in both DL and NDL at $60°·s^{-1}$ and deceleration ability. Interestingly, all correlations between eccentric KF and deceleration ability were *unclear*.

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

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

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

Only one previous study (26) has examined the relationship between eccentric KF strength and the capacity to decelerate linearly in less distance. Contrary to our findings this study found that eccentric KF strength at slower angular velocities was the best predictor (32%) of DEC-DTS. In the study by Naylor & Greig (26) the deceleration was un-anticipated. This could place greater reliance on eccentric KF strength in order to control trunk and pelvic positions, and to obtain higher and quicker levels of knee joint stabilization (35). Another possible explanation is that players in our study performed the deceleration following a 20 m sprint compared to a 10 m sprint in the protocol used by Naylor and Greig (26). Therefore, the players approach velocity and momentum were likely higher in our study making the deceleration demands considerably more challenging. In fact the average approach velocity prior to deceleration was 6.3 $m \cdot s^{-1}$, which is higher than previous studies (3.6 - 5.8 $m \cdot s^{-1}$) examining the deceleration phase prior to a COD (13,21,27).

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

Another important finding identified from the correlation analysis was concentric KE and KF strength, at faster angular velocities, in the NDL, had *almost certainly* very large relationships with DEC-TTS and DEC-DTS. Significant increases in concentric KE strength at faster angular velocities (240°$\cdot s^{-1}$) of the NDL have been found following a 5 week period of speed and agility training with an enforced deceleration (23). To our knowledge this is currently the only study to date that has specifically examined the effect of field-based, linear deceleration training on changes in unilateral KE and KF eccentric and concentric strength. While concentric strength is most frequently associated with acceleration abilities, these findings suggest that superior concentric strength —particularly at faster angular velocities— provides a substantial contribution to the capacity to decelerate rapidly in less time and distance.

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

A potential limitation of our study is that the players could pre-plan their deceleration strategy. In match play it is likely most decelerations are performed in unanticipated situations, thereby posing more sophisticated challenges to motor control. It would be useful to understand the physical capacities required to decelerate maximally under reactive unanticipated conditions. Furthermore, IKD strength assessment could be perceived to be a less ‘functional’ assessment. However, we suggest that IKD strength assessment poses similar load characteristics to those experienced during a maximal linear deceleration. For instance during eccentric quadriceps strength assessment a postero-anterior load vector is created that is similar to that seen during the early ground contact phase of deceleration. The force vector application could have an important role in enhancing the specific strength qualities required for deceleration (12). Finally, future studies should consider additional IKD metrics, such as angle specific torque, which would reveal further insight into the specific joint angular strength qualities required for deceleration (11).

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

## PRACTICAL APPLICATIONS

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

The present study also highlights the importance of high velocity concentric strength for enhancing maximal deceleration performance. Consideration to training approaches that facilitate generation and maintenance of high knee joint extension and flexion velocities may promote superior muscle contractile properties required for quick and accurate positioning of limbs when decelerating. To achieve this coaches might consider using velocity based training devices to monitor and maintain movement velocity within specific thresholds during an exercise. This could promote favorable adaptations such as maintenance of type II muscle fibres that are critical for rapid limb movements and force production when decelerating rapidly (28).

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

## REFERENCES

1. Barnes, C, Archer, DT, Hogg, B, Bush, M, and Bradley, PS. The evolution of physical and technical performance parameters in the English Premier League. *Int J Sports Med* 35: 1095–1100, 2014.
2. Bloomfield, Jonathan; Polman, Remco; O'Donaghue, P. Deceleration movements performed during FA Premier League soccer matches. *J Sport Sci Med* Supplement: 6–11, 2007.
3. Cesar, GM and Sigward, SM. Dynamic stability during running gait termination: Differences in strategies between children and adults to control forward momentum. *Hum Mov Sci* 43: 138–145, 2015.
4. Chaabene, H, Prieske, O, Negra, Y, and Granacher, U. Change of direction speed: Toward a strength training approach with accentuated eccentric muscle actions. *Sports Med* , 2018, Ahead of print.
5. Chaouachi, A, Manzi, V, Chaalali, A, Wong, DP, Chamari, K, and Castagna, C. Determinants analysis of change-of-direction ability in elite soccer players. *J Strength Cond Res* 26: 2667–76, 2012.

6. Colby, S, Francisco, A, Yu, B, Kirkendall, D, Finch, M, and Garrett, W. Electromyographic and kinematic analysis of cutting maneuvers implications for anterior cruciate ligament injury. *Am J Sports Med* 28: 234–240, 2000.

7. Cronin, J, Ross, A, Bedford, C, Crosland, R, Birch, W, and Fathers, S. Deceleration forces associated with a novel cable pulling exercise. *J Aust Strength Cond Cond* 24: 16–19, 2016.

8. Cronin, JB and Templeton, RL. Timing light height affects sprint times. *J Strength Cond Res* 22: 318–20, 2008.

9. Delextrat, a., Gregory, J, and Cohen, D. The use of the functional H:Q ratio to assess fatigue in soccer. *Int J Sports Med* 31: 192–197, 2010.

10. Draganidis, D, Chatzinikolaou, A, Avloniti, A, Barbero-Álvarez, JC, Mohr, M, Malliou, P, et al. Recovery kinetics of knee flexor and extensor strength after a football match. *PLoS One* 10: e0128072, 2015.

11. Eustace, SJ, Page, RM, and Greig, M. Contemporary approaches to isokinetic strength assessments in professional football players. *Sci Med Footb* 1: 251–257, 2017.

12. Gonzalo-Skok, O, Tous-Fajardo, J, Valero-Campo, C, Berzosa, C, Bataller, AV, Arjol-Serrano, JL, et al. Eccentric overload training in team-sports functional performance: Constant bilateral vertical vs. variable unilateral multidirectional movements. *Int J Sports Physiol Perform* 12: 951–958, 2016.

13. Havens, KL and Sigward, SM. Whole body mechanics differ among running and cutting maneuvers in skilled athletes. *Gait Posture* 42: 240–5, 2015.

14. Hewit, J, Cronin, J, Button, C, and Hume, P. Understanding Deceleration in Sport. *Strength Cond J* 33: 47–52, 2011.

15. Hopkins, WG. A scale of magnitudes for effect statistics. *Sportscience* , 2002.

Retrieved from: http://www.sportsci.org/resource/stats/effectmag.html

16. Hopkins, WG. A spreadsheet for deriving a confidence interval, mechanistic inference and clinical inference from a p value. *Sportscience* 11: 16–20, 2007.

17. de Hoyo, M, Cohen, DD, Sañudo, B, Carrasco, L, Álvarez-Mesa, A, del Ojo, JJ, et al. Influence of football match time–motion parameters on recovery time course of muscle damage and jump ability. *J Sports Sci* 34: 1–8, 2016.

18. de Hoyo, M, Sañudo, B, Carrasco, L, Mateo-Cortes, J, Domínguez-Cobo, S, Fernandes, O, et al. Effects of 10-week eccentric overload training on kinetic parameters during change of direction in football players. *J Sports Sci* 34: 1380–7, 2016.

19. Jones, P, Bampouras, TM, and Marrin, K. An investigation into the physical determinants of change of direction speed. *J Sports Med Phys Fitness* 49: 97–104, 2009.

20. Jones, P, Thomas, C, Dos'Santos, T, McMahon, J, and Graham-Smith, P. The Role of Eccentric Strength in 180° Turns in Female Soccer Players. *Sports* 5: 42, 2017.

21. Jones, P, Thomas, C, Dos'Santos, T, McMahon, J, and Graham-Smith, P. The role of eccentric strength in 180° turns in female soccer players. *Sports* 5: 42, 2017.

22. Kovacs, MS, Roetert, EP, and Ellenbecker, TS. Efficient deceleration: The forgotten factor in tennis-specific training. *Strength Cond J* 37: 92–103, 2015.

23. Lockie, RG, Schultz, AB, Callaghan, SJ, and Jeffriess, MD. The effects of traditional and enforced stopping speed and agility training on multidirectional speed and athletic function. *J Strength Cond Res* 28: 1538–51, 2014.

24. Lockie, RG, Schultz, AB, Jeffriess, MD, and Callaghan, SJ. The relationship

between bilateral differences of knee flexor and extensor isokinetic strength and multi-directional speed. *Isokinet Exerc Sci* 20: 211–219, 2012.

25. Mara, JK, Thompson, KG, Pumpa, KL, and Morgan, S. The acceleration and deceleration profiles of elite female soccer players during competitive matches. *J Sci Med Sport* 1–6, 2016.

26. Naylor, J and Greig, M. A hierarchical model of factors influencing a battery of agility tests. *J Sports Med Phys Fitness* 55: 1329–35, 2015.

27. Nedergaard, NJ, Kersting, U, and Lake, M. Using accelerometry to quantify deceleration during a high-intensity soccer turning manoeuvre. *J Sports Sci* 32: 1897–1905, 2014.

28. Pareja-Blanco, F, Rodríguez-Rosell, D, Sánchez-Medina, L, Sanchis-Moysi, J, Dorado, C, Mora-Custodio, R, et al. Effects of velocity loss during resistance training on athletic performance, strength gains and muscle adaptations. *Scand J Med Sci Sport* 724–735, 2017.

29. Petrakos, G, Morin, JB, and Egan, B. Resisted sled sprint training to improve sprint performance: A systematic review. *Sport Med* 46: 381–400, 2016.

30. Rae, DE, Stephenson, KJ, and Roden, LC. Factors to consider when assessing diurnal variation in sports performance: the influence of chronotype and habitual training time-of-day. *Eur J Appl Physiol* 115: 1339–1349, 2015.

31. Read, PJ, Oliver, JL, De Ste Croix, MBA, Myer, GD, and Lloyd, RS. Neuromuscular risk factors for knee and ankle ligament injuries in male youth soccer players. *Sport Med* 46: 1059–1066, 2016.

32. Rumpf, MC, Lockie, RG, Cronin, JB, and Jalilvand, F. Effect of different sprint training methods on sprint performance over various distances: A brief review. *J Strength Cond Res* 30: 1767–85, 2016.

33. Russell, M, Sparkes, W, Northeast, J, Cook, CJ, Love, TD, Bracken, RM, et al. Changes in acceleration and deceleration capacity throughout professional soccer match-play. *J Strength Cond Res* 30: 2839–44, 2016.

34. Seitz, LB, Reyes, A, Tran, TT, de Villarreal, ES, and Haff, GG. Increases in lower-body strength transfer positively to sprint performance: A systematic review with meta-analysis. *Sport Med* 44: 1693–1702, 2014.

35. Spiteri, T, Newton, RU, and Nimphius, S. Neuromuscular strategies contributing to faster multidirectional agility performance. *J Electromyogr Kinesiol* 25: 629–36, 2015.

36. Spiteri, T, Nimphius, S, Hart, NH, Specos, C, Sheppard, JM, and Newton, RU. Contribution of strength characteristics to change of direction and agility performance in female basketball athletes. *J Strength Cond Res* 28: 2415–23, 2014.

37. Tierney, PJ, Young, A, Clarke, ND, and Duncan, MJ. Match play demands of 11 versus 11 professional football using Global Positioning System tracking: Variations across common playing formations. *Hum Mov Sci* 49: 1–8, 2016.

38. Tillin, NA, Pain, MTG, and Folland, JP. Contraction type influences the human ability to use the available torque capacity of skeletal muscle during explosive efforts. *Proc R Soc B Biol Sci* 279: 2106–2115, 2012.

39. Tinwala, F, Cronin, J, Haemmerle, E, and Ross, A. Eccentric strength training: A review of the available technology. *Strength Cond J* 39: 32–47, 2017.

40. Vanrenterghem, J, Venables, E, Pataky, T, and Robinson, MA. The effect of running speed on knee mechanical loading in females during side cutting. *J Biomech* 45: 2444–9, 2012.

**FIGURE CAPTIONS**

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

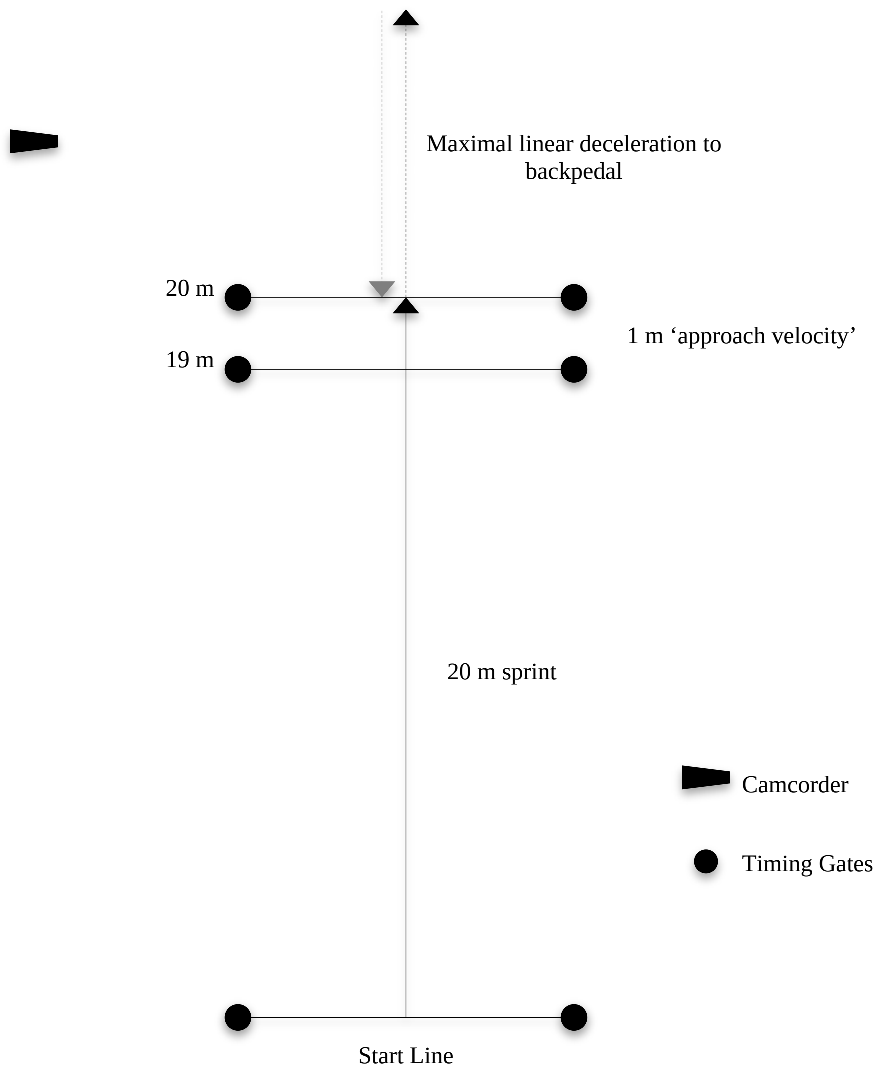
Maximal linear deceleration to backpedal
20 m
19 m
1 m ‘approach velocity’
20 m sprint
Camcorder
Timing Gates
Start Line

**Table 1.** Sprint and maximal linear deceleration performance scores

| **Variables** | **Mean ± SD** | **90% CI** |
|---|---|---|
| **Sprint** | | |
| 20 m (s)* | 3.12 ± 0.12 | 3.06 – 3.18 |
| 30 m (s) | 4.26 ± 0.12 | 4.20 – 4.32 |
| **Deceleration** | | |
| Approach Velocity ($m \cdot s^{-1}$) | 6.31 ± 0.48 | 6.08 – 6.53 |
| DEC-DTS (m) | 3.7 ± 0.52 | 3.45 – 3.95 |
| DEC-TTS (s) | 1.03 ± 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°·s$^{-1}$) and faster (180°·s$^{-1}$) angular velocities

| Angular velocity | IKD strength capacities | DL (mean + SD) | 90% CI | NDL (mean + SD) | 90% CI |
|---|---|---|---|---|---|
| 60°·s$^{-1}$ | ConKE | 193.71 + 32.24 | 178.45 – 208.98 | 189.86 + 25.77 | 177.66 – 202.06 |
| | ConFK | 101.71 + 18.75 | 92.84 – 110.59 | 100.36 + 17.58 | 92.04 – 108.68 |
| | EccKE | 223.14 + 40.79 | 203.84 – 242.45 | 214.79 + 53.39 | 189.51 – 240.06 |
| | EccKF | 124.71 + 28.49 | 111.23 – 138.20 | 121.36 + 23.09 | 110.43 – 132.29 |
| 180°·s$^{-1}$ | ConKE | 133.07 + 29.61 | 119.06 – 147.09 | 131.29 + 25.92 | 119.02 – 143.55 |
| | ConKF | 74.00 + 18.75 | 92.84 – 110.59 | 72.79 + 17.37 | 64.56 – 81.00 |
| | EccKE | 193.86 + 41.32 | 174.30 – 213.42 | 189.21 + 33.21 | 173.50 – 204.93 |
| | EccKF | 119.86 + 32.78 | 104.34 – 135.37 | 111.86 + 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 | *Almost certain* |
| $EccKE_{60}$ | - 0.64 (-0.26 to -0.85) | 41 (7-72) | Large | 0/1/99 | *Very Likely* |
| $ConKF_{180}$ | - 0.61 (-0.21 to -0.84) | 37 (4-71) | Large | 0/2/98 | *Very Likely* |
| $ConKF_{60}$ | - 0.55 (-0.12 to -0.81) | 30 (1-66) | Large | 1/3/96 | *Very Likely* |
| ***DL*** | | | | | |
| $EccKE_{60}$ | - 0.63 (-0.26 to -0.85) | 40 (6-72) | Large | 0/2/98 | *Very Likely* |
| $ConKE_{180}$ | - 0.54 (-0.11 to -0.80) | 29 (1-64) | Large | 1/4/95 | *Very Likely* |

[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 $EccKF_{60}$; NDL $EccKE_{180}$; NDL $ConKE_{60}$; DL $EccKF_{60}$; DL $EccKF_{180}$; DL $ConKE_{60}$; DL $ConKF_{60}$; DL $ConKF_{180}$
*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 = $60°\cdot s^{-1}$; 180 = $180°\cdot s^{-1}$.

**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 | *Almost certain* |
| $ConKF_{60}$ | -0.7 (-0.36 to -0.88) | 49 (13-77) | Very large | 0/1/99 | *Almost certain* |
| $ConKE_{180}$ | -0.64 (-0.26 to -0.85) | 41 (7-72) | Large | 0/1/99 | *Very likely* |
| $EccKE_{60}$ | -0.55 (-0.12 to -0.80) | 30 (1-66) | Large | 1/3/96 | *Very likely* |
| **DL** | | | | | |
| $ConKE_{180}$ | -0.55 (-0.12 to -0.81) | 30 (1-66) | Large | 1/3/96 | *Very likely* |
| $EccKE_{60}$ | -0.54 (-0.11 to -0.80) | 29 (1-64) | Large | 1/4/96 | *Very likely* |
| $ConKF_{180}$ | -0.54 (-0.11 to -0.80) | 29 (1-64) | Large | 1/4/96 | *Very likely* |

[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 $EccKF_{60}$; NDL $EccKE_{180}$; NDL $ConKE_{60}$; DL $EccKF_{60}$; DL $EccKF_{180}$; DL $ConKE_{60}$; DL $ConKF_{60}$.
*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 = $60°\cdot s^{-1}$; 180 = $180°\cdot s^{-1}$.