Jones, S., Mullen, R., Clair, Z., Wrigley, R., Andersen, T. E., Williams, M. (2021). Field based lower limb strength tests provide insight into sprint and change of direction ability in academy footballers. *Scandinavian Journal of Medicine & Science in Sports, 31*(12), 2178-2186. http://dx.doi.org/10.1111/sms.14039

Mr Steven Jones

Article type: Original Article

Title: Strength tests for the hip and groin provide insight into sprint and change of direction ability in academy footballers

Running head: Strength, sprint and change of direction in academy football

Authors:
Steven Jones[1, 6, 7], Rich Mullen[2], Zoe Clair[5], Russ Wrigley[4], Thor Einar Andersen[3], Morgan Williams[1]

Institutions/Affiliations:
[1]School of Health, Sport and Professional Practice, Faculty of Life Sciences and Education, University South Wales, Pontypridd, Wales
[2]School of Sport, Health and Exercise Sciences, Brunel University London, UK
[3]Oslo Sports Trauma Research Center, Department of Sports Medicine, Norwegian School of Sport Sciences, Oslo, Norway
[4]Blackburn Rovers Youth Academy, Blackburn Rovers Football Club, Blackburn, UK
[5]Blackburn Rovers Ladies Football Club, Blackburn, UK
[6]VBV De Graafschap Youth Academy, VBV De Graafschap Football Club, Doetinchem, Netherlands
[7]Hubei I-star Youth Academy, Hubei I-star Football Club, Wuhan, Hubei, China

Contact author:
Steven Jones
School of Health, Sport and Professional Practice,
Faculty of Life Sciences and Education,
University South Wales.
Pontypridd,
Wales.
Email: s.k.jones@hotmail.co.uk

ACKNOWLDGMENTS

The authors would like to thank all of the players involved in this study. A special mention for all of the respective club staff that assisted in the organisation of testing, in particular Pete Aylmer, Matt Boyce, Ted Moulden, Adam Senior, Paul Wroe and Chris Jones for their assistance.

ABSTRACT
Conducting field-based strength assessments is embedded within football academy development processes. Yet, there is a limited understanding of how hip and groin strength assessments relate to vital game-based tasks such as sprinting and change of direction (COD) performance. Our aim was to explore field-based strength assessments and their relationships with both sprint and COD performance in male academy footballers. Participants (n = 146; age 14.2 ± 2.2 years; stature 166.3 ± 15.4 cm; body mass 55.6 ± 15.6 kg) performed maximal countermovement jump (CMJ), Nordic hamstring strength (NHS), isometric hip adductor (ADD)/abductor (ABD), 5m, 10m, 20m sprints and modified 505 agility test. All strength measures were allometrically scaled to account for body weight. Between limb differences were reported as imbalance scores. Principal component analysis reduced sprint and COD variables to a single 'running ability' component score. Scaled strength and imbalance, when controlled for age, were associated with 'running ability' (adjusted $R^2 = 0.78$, $P < 0.001$). Significant effects on 'running ability' included: age, CMJ-impulse, NHS and hip-ADD. When the sprint and COD variables were explored independently, age and CMJ-impulse featured in all sprint and COD models. For 10m and 20m sprint distances, hip-ADD emerged as a significant effect. Mean 505 performance was explained by age, CMJ-impulse, hip-ADD, but also with the addition of NHS. Our findings suggest that insight into the underpinning strength qualities of 'running ability' of academy footballers can be obtained from a suite of field-based tests.

KEYWORDS
soccer, eccentric strength, impulse, sprint, change of direction, youth

INTRODUCTION

Worldwide, football academies exist to develop talented young players. These academies select aspiring young footballers and prepare them through structured training and competition for the subsequent development cycles and ultimately, professional football. For players to transition through these development cycles it is important that they have sufficient exposure to training and competition so they can improve on tactical, technical, physical and psychological qualities. Given their influence on game outcomes [1], sprinting and change of direction (COD) are important football fitness components used for talent identification and development.[2] Underpinning sprinting and COD are strength qualities that form the basis of regular strength assessments for academy footballers.[3] Recently, novel field-based hamstring, hip and groin strength assessment devices (Nordbord(patented) and Force Frame™, Vald Performance, Albion, Australia) have been developed that allow rapid, reliable and valid strength testing. [4–6] Research has previously reported strength data for academy footballers using these devices [7], but it remains to be seen if these measures provide an insight into sprint or COD performance in this population. One study, using a replica device, reported an inverse relationship (r = -0.52; 95% CI = -0.36 to -0.63) between normalised Nordic hamstring strength (NHS) and 20m sprint time [8] however, that study [8] did not investigate the association between NHS and COD. The association between eccentric hamstring strength and COD performance has been supported in the literature [9–11], but these data are exclusively centred around adult cohorts and laboratory assessments.

The countermovement jump (CMJ) has also been an established assessment in academy football [12, 13]; however, its association with sprint performance in football remains unclear, with some studies reporting meaningful relationships [12–14] and others finding the opposite.[15–17] Similarly, the relationship between CMJ and COD ability is also unclear [17–21], with little information relating specifically to academy footballers. Potential associations between hip-adduction (ADD) and abduction (ABD) strength, have featured to a lesser extent in the sprint and COD literature, although their involvement has been articulated and evidenced by imaging studies.[22, 23] Given, the limitations outlined above, understanding how field-based hip and groin strength exercises relate to game-based tasks such as sprinting and COD would help to inform those tasked with physical preparation of academy footballers to develop a strength profile and target specific individual needs. The aims of our investigation were therefore, (1) to explore the relationships between a combination of field-based strength assessments with sprint and COD performance; and (2) present age-group data for all tests.

MATERIAL AND METHODS

Participants

All participants invited to volunteer for this study were contracted to one of two English Premier League academies, attending between 5-7 training sessions and taking part in one competitive game per week at the time of testing. Descriptive statistics for the participants are provided in Table 1. Participants were included in the study if they were available for unrestricted training and competitive games at the time of testing as determined by academy medical staff (i.e., club physiotherapists or doctors). One hundred and forty-six out of a possible 169 academy footballers participated in this study. Twenty-three participants were excluded based on the inclusion criteria. This study was conducted in accordance with the declaration of Helsinki and approved by the ethics committee of University of South Wales (18JA0401HR). Parental consent and player assent were obtained prior to testing.

INSERT Table 1

Experimental design

All testing was carried out over a two-day period at the mid-way point of season 2018/19. On the first day, after a standardised warm-up that consisted of 15-minutes jogging and dynamic flexibility, players performed a single set of three maximal repetitions of isometric hip-ADD, ABD and bilateral NHS tests. Maximal NHS and isometric hip strength were defined as the highest score recorded from the three attempts for each test. No load was added to the Nordic exercise, all players had previous experience of all strength tests and underwent additional test familiarization during 6-10 weeks before the start of testing. Day two consisted of performing the standardised warm up, followed by CMJ tests, 20m sprints tests split at 5m and 10m, along with three trials (per side) of a modified 505 run.[24] All tests were undertaken on an indoor 3-G surface. To address order effects, each group of players completed each station in a random order, and, consistent with previous research [17], rested for 15-minutes between each testing station. Cleated footwear worn for competitive games and training was used by all players for sprint and CMJ assessments. All tests were completed after a rest day and prior to any training to limit fatigue effects.

Nordic hamstring strength

Assessment of NHS was performed using a Nordbord(patented) (Vald Performance, Albion, Australia), which has been previously demonstrated very good reliability (intraclass correlation coefficient = 0.83-0.90; typical error, 21.7-27.5 N; typical error as a coefficient of variation, 5.8% - 8.5%; minimal detectable change at a 95% confidence level, 60.1-76.2 N [4]), participants knelt on the Nordbord, with the ankles secured immediately superior to the lateral malleolus by individual ankle hooks. Investigators ensured strict adherence to technique and players received verbal encouragement throughout each repetition to encourage maximal effort. Eccentric peak and mean hamstring force (N) were recorded while between limb imbalance ration was converted to a percentage strength imbalance.[4]

Isometric hip strength

Isometric hip-ADD and ABD strength was assessed using Force Frame™ (Vald Performance Albion, Australia) and has been shown to be reliable (smallest worthwhile change = 5.0N; CV = 6.6% [6]). Players first adopted a standardised position as described by Ryan et al.[6], where they lay in a supine position. For the isometric hip-ADD test, the femoral and tibial condyles were positioned central to the force pads. For the isometric hip-ABD test, the lateral femoral condyle and head of the fibula were central to the outer force pads. To standardise position, the investigator ensured that all players-maintained contact with the floor, not raising the legs, tilting the pelvis or lifting their heads. Isometric hip strength was determined for each leg from the peak and mean force during the best of three repetitions of 5-seconds (s), with a 10 s rest period between efforts.[5, 6] The between limb imbalance for hip-ADD and ABD was calculated as per previous work.[25]

Countermovement jump testing

All players were given standardised instructions to stand on the force platform (HUR Labs Force Platform 3.8.0.2, Finland) with 1-second period of quiet standing and then asked to jump on the command of the investigator. The force platform was calibrated before testing using masses that were tracible to national standards. All players performed three CMJ with 1-minute recovery between repetitions, with hand on hips and squatting to self-selected depth before immediately extending into a maximal vertical jump. The highest jump was recorded for the data analysis and jump impulse (CMJ-impulse) determined post-hoc, so all measures were expressed as force.

Sprint testing

The players performed three maximal 20m sprints with 1-minute recovery between each sprint. Each sprint started 30cm behind the start line from a two-point stance and was recorded using light gates (Brower Timing System, Salt Lake City, UT, USA) at 5m, 10m and 20m. For all sprints, players were instructed to run as fast as possible all the way through the timing gates. A flying 10m sprint time was determined by the time taken to sprint between 10m and 20m light gates, removing the initial acceleration. The fastest time (s) for 5m, 10m and 20m sprint was used for analysis.

Modified 505 testing

Every trial started 30cm behind the start line from a two-point stance and was timed using light gates (Brower Timing System, Salt Lake City, UT, USA) at 0m and 5m. As described by Gabbett et al. [24], players were instructed to accelerate as quickly as possible, turn on the line and return through the timing gate. The left, right and mean time (s) of the two trials was used for analysis.

Control for the Effects of Body Size

To control for the effects of body weight on strength measures an allometric modelling approach was used based on the recommendations of Nevill and Holder.[26] This was preceded by Pearson product moment correlation coefficients to determine the degree of relationship between body weight and strength variables. Logarithmic transformation was performed on each strength variable and body weight. A linear regression analysis was then applied to the logarithmic transformed data to determine the regression coefficients. Allometric scaled variables were then obtained using the following equation:

$$Allometric\ Scaled\ Variable = \frac{Absolute\ Variable}{BW^b}$$

Where BW = body weight (N) and b = coefficient obtained from the regression analysis.

Statistical analysis

Descriptive data are presented as means and standard deviations. All statistical analyses were performed using JMP V.15.02 Pro Statistical Discovery Software (SAS Inc., Cart, North Carolina USA) and data screened for the appropriate assumptions. Body weight was related to all strength measures (R^2 range = 0.58 to 0.95, P < 0.001). Following allometric scaling the association was removed (R^2 < 0.001; P range = 0.82 to 0.98). Log strength score by log body weight provided the slope using equations that are displayed in online supplementary information.

To reduce the dimensionality of the sprint and COD variables and to encapsulate a measure of ‘running ability’, principal component analysis (PCA) was used. For an explanation of PCA for similar purposes, please refer to Bourne et al.[25] Multiple regression was used to predict the principal component for ‘running ability’, which included the allometrically scaled strength measures (i.e., CMJ-impulse, NHS, hip-ADD and ABD forces) and the associated between-limb imbalance scores as the independent variables, while controlling for age (years). For descriptive purposes only, an exploration into the association of all strength and imbalance measures with each sprint distance (5m, 10m, 20m and flying 10m) and COD (mean score of left and right), was completed by a series of follow-up multiple regression analyses. To provide perspective for practice and assist with the interpretation of the findings, decision tree induction (DTI) was also used. Age-group and all scaled strength measures were included in DTI to predict the 'running ability' component score derived from PCA.

RESULTS

Descriptive statistics for strength and 'running ability' variables are shown by age-group in Table 2 and for all age groups combined, see online supplementary material 1.

INSERT Table 2

Sprint and COD measures were highly correlated (range r = 0.64 to 0.92; see supplementary materials), justifying the use of PCA to reduce the dataset and form a single variable representing 'running ability'. All linear sprint/COD variables were entered and loaded on 1 principal component (see loading matrix; coefficients ranged from 0.82 to 0.97 [online supplementary material 2 and 3]).

Multiple regression analysis

Age, strength and imbalance measures were included in the multiple regression model to predict the 'running ability' component score. The whole model predicted 'running ability' (adjusted R^2 = 0.78, P <0.001). Age; scaled CMJ-impulse; NHS and hip-ADD were significant main effects (Table 3). When the sprint and COD variables were considered separately, age and allometrically scaled CMJ-impulse predicted 5m sprint performance (adjusted R^2 = 0.59, P <0.0001). Both 10m and 20m sprint times (s) were predicted by age, allometrically scaled CMJ-impulse and hip-ADD (adjusted R^2 = 0.59, P <0.001 and R^2 = 0.71, P <0.001, respectively). Mean 505 (COD) performance was predicted (adjusted R^2 = 0.70, P <0.001) by age, allometrically scaled CMJ-impulse, hip-ADD and NHS. Finally, flying 10m sprint time was predicted (adjusted R^2 = 0.52, P <0.001) by age alone. Imbalance scores for strength (NHS, hip-ADD and ABD) had little effect on sprint/COD performance, see Table 3.

INSERT Table 3

Decision Tree Induction

The variables that featured in the DTI model in order of contribution were age-group, scaled CMJ-impulse, NHS and hip-ADD (Figure 1). Of note, the fastest group ('running ability' = -3.213±0.262) was characterised by players in the older cohorts (under-16 and under-18), with scaled CMJ-impulse ≥0.031 $Ns{\cdot}BW^{b-1}$, hip-ADD ≥0.033 $N{\cdot}BW^{b-1}$ and NHS ≥0.307 $N{\cdot}BW^{b-1}$. Whereas, the slowest group ('running ability' = 3.61±1.23) consisted of under-10 and under-11 players with scaled CMJ-impulse of <0.030 $Ns{\cdot}BW^{b-1}$.

INSERT Figure 1

DISCUSSION

The ability of academy footballers to cover short distances and change direction quickly is an essential component of on-field performance and improving this aspect of performance is a focus of training. We found that 'running ability' was associated with age, and allometrically scaled strength measures obtained from a suite of field-based strength assessments, which included scaled CMJ-impulse, hip-ADD and NHS. Further exploration highlighted that scaled CMJ-impulse and hip-ADD featured in the sprint and COD performances. Nordic hamstring strength contributed solely to COD performance and muscle imbalances had a little impact on ‘running ability’ in academy footballers. These findings suggest the underpinning strength qualities that explain ‘running ability’ can be assessed from the suite of field-based assessments examined here.

Our data suggest that scaled CMJ-impulse score was the major contributor to ‘running ability’ in academy footballers. Previously, moderate to strong correlations between CMJ and linear sprint performance in high school and collegiate [12] and academy [13] footballers were reported, in line with the findings of this study. Linear sprint and CMJ are both characterised by triple extension movement patterns to impart force for propulsion. The importance of muscle groups (i.e., gluteal, quadricep, hamstring, and triceps surae) used to rapidly extend the hip, knee and ankle joints during sprinting [23] and CMJ [22] has been previously confirmed using magnetic resonance imaging (MRI). Our data also indicated that when controlled for age, scaled CMJ-impulse contributed to COD ability, which is also consistent with previous research.[17, 20, 21, 27] The coordinated joint flexion to extension sequence of the hip-knee-ankle in the CMJ is dominated by the concentric muscles actions, similar to that observed during the push-off phase of sprinting and during the turn when changing direction.[17] The present study differed to previous reports [8, 13] in that the addition of scaled hip-ADD strength and NHS increased the ability of CMJ-impulse to account for COD performance. These findings suggest that a suite of strength tests measures could be used to gain a more in-depth insight into the academy footballer’s strength base before decisions about strength training to improve COD and sprint performance are made.

The current investigation demonstrated a positive contribution of scaled NHS to speed in academy footballers (Table 3). Previous research has reported links to greater NHS and faster sprint [8, 28–31] and COD [31] performance. Markovic et al. [8] found that NHS accounted for 27% of the variance in 20m sprint performance in youth athletes; possibly the result of architectural force generating and muscle volume [32] adaptations connected with NHS training. Scaled NHS did not feature significantly in any of our predictive sprint models when each distance was considered separately, suggesting that the importance of NHS and sprint speed in academy footballers may be overestimated when the contribution of additional strength variables are not considered. Limitations around single strength measures and correlational analysis could offer a potential reason for heterogeneity between our findings and those of previous research.[8, 28–31] Nordic hamstring exercises are viewed as supra-maximal [33], suggesting a closer relationship with maximal strength and limited impact on sprinting when the time to express force is constrained to short intervals. Scaled NHS, CMJ-impulse and hip-ADD all contributed to the COD performance. In support of our findings, eccentric hamstring strength derived from isokinetic assessments has also been shown to be significantly correlated with COD performance in male (r =0.60) and female (r =0.63) cohorts.[10, 11] The importance of eccentric hamstring strength has been established due to its role in stabilising the knee [11], force absorption [9], controlling trunk flexion and assisting whole body deceleration.[34] Such factors have been proposed to combine and assist eccentrically stronger athletes enter into the COD at a greater speed. [11, 35] Given the importance of eccentric strength of the hamstrings during COD movement tasks and the contribution of scaled NHS and COD performance in the present study, inclusion of the NHS test in a battery of assessments used to assist the development of academy footballers would appear to be justified.

Previously, normalised muscle volume of hip-ADD measured by MRI was observed to be valuable for CMJ [22] and sprint [23] performance. The mid-swing phase of sprinting requires deep hip flexion, which creates a longer moment arm for the hip-ADD compared to other hip muscles.[36] This mechanical advantage increases their contribution to hip extension during the late swing to early contact phase [37] offering another potential mechanism to explain our findings. Furthermore, scaled strength imbalance measures did not feature in any of the models used in the present study. Past research using single leg CMJ in academy footballers, found that inter-limb imbalances negatively impacted performance.[38] When jumping, inter-limb imbalances might accumulate over a number of joints and muscle groups increasing their magnitude so that they impact on performance. However, we assessed individual muscles (e.g., hamstrings, hip-ADD/ABD) at a single joint and the imbalances that were detected in this study may not be of the level required to impact on running abilities. Further work is required in this area to validate the impact of specific muscle imbalance on running performance in academy footballers. Such work should include limb length and other body asymmetries as these may also affect running abilities in cohorts that are undergoing growth and maturation.

Methodological considerations

Since the current data was collected in-season in two professional football academy settings, it must be acknowledged that there are limitations to the present study associated with the inherent challenges of conducting research in the field. For example, some players might not have reported non-time loss injuries like the heel, knee and groin pain. Often players can continue to train and compete with such issues [39, 40], but the impact on sprint, COD and lower limb strength remains unclear. The lack of maturational offset could be viewed by some as another weakness, but maturational equations are associated with limitations.[41] With this in mind, to account for the significant variation of body weights observed in our data, allometric scaling of strength and CMJ variables was used.[26] A further weakness could be the time constraints for testing a large cohort prior to in-season training. The testing schedule might have provided insufficient recovery periods between maximal contractions, but the protocols used are consistent with past research.[5–7] Testing sprint and COD performance on a 3G playing surface could also be seen as limitation, since matches are usually played on natural grass and this may have altered the players' normal movement patterns. However, presenting in-season strength and performance data of a large sample size of academy footballers in an applied setting could also be viewed as an advantage as it addresses the paucity of research in this population.[7, 42]

PERSPECTIVES

Too often linear sprinting for football is considered important when the focus should be placed on the ability to cover short distances, involving COD, quickly. The associations between different strength measures and 'running ability' found in this study demonstrate the importance of considering a suite of field-based tests. To offer a deeper perspective on the results a DTI analysis was included to provide those working in football academies with a frame of reference for the development of strength by providing age-group relevant thresholds that differentiate between the fastest and slowest players. It is important to note that the values presented in our DTI should be interpreted with caution since other youth cohort's scores may vary as there is always some variation in training regimes. Future work is required to validate strength thresholds further research could also identify strength losses and their negative impact on 'running ability'.

AVAILABILITY OF DATA

The data that supports the findings of this study are available from the corresponding author upon reasonable request.

CONFLICT OF INTEREST

Morgan Williams reports receiving fees from VALD Performance, for work on that company's research committee not related to the current study. Steven Jones, Zoe Clair, Russ Wrigley, Rich Mullen and Thor Einar Andersen declare that they have no conflicts of interest related to this article. No other competing interests are declared.

REFERENCES

1. Mujika, I, Santisteban, J, Impellizzeri, FM, Castagna, C. Fitness determinants of success in men’s and women’s football. *J Sports Sci*. 2009;27:107-114.
2. Le Gall, F, Carling, C, Williams, M, Reilly, T. Anthropometric and fitness characteristics of international, professional and amateur male graduate soccer players from an elite youth academy. *J Sci Med Sport*. 2010;13:90-95.
3. Paul, DJ, Nassis, GP. Testing strength and power in soccer players. *J Strength Cond Res*. 2015;29:1748-1758.
4. Opar, DA, Piatkowski, T, Williams, MD, Shield, AJ. A novel device using the Nordic hamstring exercise to assess eccentric knee flexor strength: a reliability and retrospective injury study. *J Orthop Sports Phys Ther*. 2013;43:636-640.
5. O’Brien, M, Bourne, M, Heerey, J et al. A novel device to assess hip strength: concurrent validity and normative values in male athletes. *Phys Ther Sport*. 2019;35:63-68.
6. Ryan, S, Kempton, T, Pacecca, E, Coutts, AJ. Measurement properties of an adductor strength assessment system in professional Australian Footballers. *Int J Sports Physiol Perform*. 20181-13.
7. Jones, S, Clair, Z, Wrigley, R et al. Strength development and non-contact lower limb injury in academy footballers across age groups. *Scand J Med Sci Sports*. 2020doi: 10.11/sms.13889.
8. Markovic, G, Sarabon, N, Boban, F et al. Nordic hamstring strength of highly trained youth football players and its relation to sprint performance. *J Strength Cond Res*.. 2018doi: 10.1519/JSC.0000000000002800.
9. Lockie, RG, Schultz, AB, Jeffriess, MD, Callaghan, SJ. The relationship between bilateral differences of knee flexor and extensor isokinetic strength and multi-directional speed. *Isokinet Exerc Sci*. 2012;20:211-219.
10. Naylor, J, Greig, M. A hierarchical model of factors influencing a battery of agility tests. *J Sports Med Phys Fitness*. 2015;55:1329-1335.
11. Jones, PA, Thomas, C, Dos’Santos, T et al. The role of eccentric strength in 180° turns in female soccer players. *Sports* (Basel). 2017;5:42.
12. Vescovi, JD, Mcguigan, MR. Relationships between sprinting, agility, and jump ability in female athletes. *J Sports Sci*. 2008;26:97-107.
13. Köklü, Y, Alemdaroğlu, U, Özkan, A et al. The relationship between sprint ability, agility and vertical jump performance in young soccer players. *Sci Sports*. 2015;30:e1-e5.
14. Wisloff, U, Castagna, C, Helgerud, J et al. Strong correlation of maximal squat strength with sprint performance and vertical jump height in elite soccer players. *Br J Sports Med*. 2004;38:285-288.
15. Chamari, K, Hachana, Y, Ahmed, YB et al. Field and laboratory testing in young elite soccer players. *Br J Sports Med*. 2004;38:191-196.
16. Chelly, MS, Chérif, N, Amar, MB et al. Relationships of peak leg power, 1 maximal repetition half back squat, and leg muscle volume to 5-m sprint performance of junior soccer players. *J Strength Cond Res*. 2010;24:266-271.
17. Emmonds, S, Nicholson, G, Begg, C et al. Importance of physical qualities for speed and change of direction ability in elite female soccer players. *J Strength Cond Res*. 2019;33:1669-1677.

18. Nimphius, S, Mcguigan, MR, Newton, RU. Relationship between strength, power, speed, and change of direction performance of female softball players. *J Strength Cond Res*. 2010;24:885-895.
19. Castillo-Rodríguez, A, Fernández-García, JC, Chinchilla-Minguet, JL, Carnero, EÁ. Relationship between muscular strength and sprints with changes of direction. *J Strength Cond Res*. 2012;26:725-732.
20. Chaouachi, A, Manzi, V, Chaalali, A et al. Determinants analysis of change-of-direction ability in elite soccer players. *J Strength Cond Res*. 2012;26:2667-2676.
21. Pereira, LA, Nimphius, S, Kobal, R et al. Relationship between change of direction, speed, and power in male and female National Olympic Team Handball Athletes. *J Strength Cond Res*. 2018;32:2987-2994.
22. Xie, T, Crump, KB, Ni, R et al. Quantitative relationships between individual lower-limb muscle volumes and jump and sprint performances of basketball players. *J Strength Cond Res*. 2020;34:623-631.
23. Handsfield, GG, Knaus, KR, Fiorentino, NM et al. Adding muscle where you need it: non-uniform hypertrophy patterns in elite sprinters. *Scand J Med Sci Sports*. 2017;27:1050-1060.
24. Gabbett, TJ, Kelly, JN, Sheppard, JM. Speed, change of direction speed, and reactive agility of rugby league players. *J Strength Cond Res*. 2008;22:174-181.
25. Bourne, MN, Williams, M, Jackson, J et al. Preseason hip/groin strength and HAGOS scores are associated with subsequent injury in professional male soccer players. *J Orthop Sports Phys Ther*. 2020;50:234-242.
26. Nevill, AM, Holder, RL. Scaling, normalizing and per ration standards: an allometric modeling approach. *J Appl Physiol*. 1995;79:1027-1031.
27. Castillo-Rodríguez, A, Fernández-García, JC, Chinchilla-Minguet, JL, Carnero, EÁ. Relationship between muscular strength and sprints with changes of direction. *J Strength Cond Res*. 2012;26:725-732.
28. Mjølsnes, R, Arnason, A, Østhagen, T et al. A 10-week randmized trial comparing eccentric vs. concentric hamstring strength training in well-trained soccer players. *Scand J Med Sci Sport*s. 2004;14:311-317.
29. Krommes, K, Petersen, J, Nielsen, MB et al. Sprint and jump performance in elite male soccer players following a 10-week Nordic hamstring exercise protocol: a randomised pilot study. *BMC Res Notes*. 2017;10:669.
30. Ishøi, L, Hölmich, P, Aagaard, P et al. Effects of the Nordic hamstring exercise on sprint capacity in male football players: a randomized controlled trial. *J Sports Sci*. 2018;36:1663-1672.
31. Siddle, J, Greig, M, Weaver, K et al. Acute adaptations and subsequent preservation of strength and speed measures following a Nordic hamstring curl intervention: a randomised controlled trial. *J Sports Sci*. 2019;37:911-920.
32. Bourne, MN, Duhig, SJ, Timmins, RG et al. Impact of the Nordic hamstring and hip extension exercises on hamstring architecture and morphology: implications for injury prevention. *Br J Sports Med*. 2017;51:469-477.
33. Cuthbert, M, Ripley, N, McMahon, JJ et al. The effect of Nordic Hamstring Exercise intervention volume on eccentric strength and muscle architecture adaptations: a systematic review and meta-analyses. *Sports Med*. 2020;50:83-99.
34. Harper, DJ, Jordan, AR, Kiely, J. Relationships between eccentric and concentric knee strength capacities and maximal linear deceleration ability in male academy soccer players. *J Strength Cond Res*. 201810.1519/JSC.0000000000002739.
35. Chaabene H. Change of direction tasks: does the eccentric muscle contraction really matter? *Arch Sports Med*. 2017;1:1-2.

36. Delp, SL, Maloney, W. Effects of hip center location on the moment-generating capacity of the muscles. *J Biomech*. 1993;26:485-499.
37. Neumann, DA. Kinesiology of the hip: a focus on muscular actions. *J Orthop Sports Phys Ther*. 2010;40:82-94.
38. Bishop, C, Brashill, C, Abbott, W et al. Jumping asymmetries are associated with speed, change of direction speed, and jump performance in elite academy soccer Players. *J Strength Cond Res*. 2019doi: 10.15/JSC.0000000000003058.
39. Clarsen, B, Bahr, R, Heymans, MW et al. The prevalence and impact of overuse injuries in five Norwegian sports: Application of a new surveillance method. *Scand J Med Sci Sports*. 2015;25:323-330.
40. Harøy, J, Clarsen, B, Thorborg, K et al. Groin problems in male soccer players are more common than previously reported. *Am J Sports Med*. 2017;45:1304-1308.
41. Malina, RM, Kozieł, SM. Validation of maturity offset in a longitudinal sample of Polish boys. *J Sports Sci*. 2014;32:424-437.
42. Jones, S, Almousa, S, Gibb, A et al. Injury incidence, prevalence and severity in high-level male youth football: a systematic review. *Sports Med*. 2019;49:1879-1899.

Table 1 Anthropometrics (mean ± SD) for 146 professional academy footballers.

Group	N	Age (Yrs)	Mass (kg)	Height (cm)
Under-10	9	10.2±0.3	31.3±4.2	137.9±4.6
Under-11	13	11.1±0.4	35.6±3.4	145.2±6.2
Under-12	19	12.0±0.2	41.7±5.4	151.6±5.1
Under-13	15	12.9±.03	47.8±7.5	159.9±8.7
Under-14	17	14.0±0.3	54.9±8.7	168.1±9.1
Under-15	24	15.0±0.2	62.0±8.5	174.1±8.2
Under-16	21	15.9±0.3	64.3±7.2	176.2±5.7
Under-18	28	17.1±0.6	74.5±6.4	181.1±5.7
Total	146	14.2±2.2	55.6±15.6	166.3±15.4

Table 2 Mean ± SD running abilities (5m, 10m, 20m, mean 505 and flying 10m [s]) and strength (allometric [N·BW^{b-1}] and absolute [N] Nordic, hip adduction, abduction and CMJ-impulse [Ns·BW^{b-1}]) scores for 146 professional academy footballers.

Age group	CMJ-impulse		Nordic hamstring strength			Hip adduction			Hip abduction			Running abilities					
	Allometric (Ns·BW^{b-1})	Absolute Ns	Allometric (N·BW^{b-1})	Absolute (N)	Imbalance (%)	Allometric (N·BW^{b-1})	Absolute (N)	Imbalance (%)	Allometric (N·BW^{b-1})	Absolute (N)	Imbalance (%)	5m (s)	10m (s)	20m (s)	Mean 505 (s)	Flying 10m (s)	PC
Under-10	0.03±0	60.2±12.4	0.29±0.05	144±26	5±10	0.29±0.09	141±46	-1±11	0.03±0.01	78±27	10±11	1.22±0.07	2.10±0.07	3.6±0.22	2.83±0.06	1.58±0.21	2.96
Under-11	0.03±0	72.8±8.9	0.29±0.04	168±19	3±12	0.29±0.05	167±30	3±5	0.02±0.01	85±29	8±16	1.25±0.06	2.11±0.10	3.65±0.22	2.84±0.11	1.54±0.19	3.03
Under-12	0.03±0	94.5±12.3	0.25±0.05	175±45	5±11	0.29±0.09	195±50	2±7	0.02±0.01	105±29	8±19	1.14±0.07	1.98±0.10	3.57±0.15	2.74±0.14	1.59±0.15	1.82
Under-13	0.03±0	113.1±27.6	0.24±0.05	188±46	5±15	0.25±0.10	192±57	-1±17	0.02±0.01	106±38	-1±22	1.08±0.06	1.90±0.08	3.33±0.16	2.70±0.13	1.42±0.08	0.46
Under-14	0.03±0	124.9±25.1	0.27±0.03	255±46	3±11	0.24±0.05	271±44	7±11	0.03±0	173±40	1±12	1.08±0.09	1.83±0.19	3.27±0.17	2.56±0.08	1.45±0.22	-0.36
Under-15	0.03±0	155.4 ±22.1	0.26±0.05	273±55	7±9	0.27±0.07	277±67	3±7	0.02±0.01	163±48	-3±15	1.05±0.06	1.83±0.09	3.25±0.18	2.52±0.06	1.38±0.08	-0.63
Under-16	0.03±0	171.5±24.8	0.29±0.04	317±51	2±9	0.31±0.09	336±80	3±8	0.02±0.01	201±50	8±16	1.02±0.06	1.77±0.08	3.08±0.08	2.45±0.12	1.28±0.06	-1.85
Under-18	0.03±0	201.6±22.6	0.28±0.04	369±58	4±11	0.34±0.05	429±52	4±8	0.03±0.01	295±64	6±10	0.99±0.06	1.73±0.07	2.98±0.11	2.44±0.07	1.24±0.05	-2.29

Table 3 Estimate, standard error and *P* values for allometrically scaled (Ns·BW^{b-1}; N·BW^{b-1}) and absolute (N) strength qualities for 146 professional academy footballers.

	Beta	Running Ability PC	5m	10m	20m	Mean 505	Flying 10m
		Estimate±Standard error; P value					
Intercept		16.48±1.44; *P* <0.0001*	1.85+0.083; *P* <0.0001**	3.033+0.107; *P* <0.001**	5.274±0.215; *P* <0.0001**	3.882+0.119; *P* <0.0001**	2.239+0.158; *P* <0.001**
Age		-0.807±0.04; *P* <0.0001**	-0.03±0.002; *P* <0.0001**	-0.053±0.003; *P* <0.001**	-0.106±0.006; *P* <0.001**	-0.062±0.003; *P* <0.0001**	-0.054±0.005; *P* <0.001**
Scaled CMJ-impulse (Ns·BW^{b-1})	^1.328	-153.37±40.85; *P* =0.0003*	-9.471±2.365; *P* =0.001**	-12.67±3.07; *P* <0.001**	-14.66±6.117; *P* =0.0182*	-10.968±3.422; *P* =0.0017*	-1.118±4.468; *P* =0.8028
Scaled Nordic hamstring strength (N·BW^{b-1})	^1.0873	-5.081±2.54; *P* =0.0481	-0.183±0.139; *P* =0.1918	-0.296±0.181; *P* =0.1034	-0.512±0.381; *P* =0.1813	-0.545±0.201; *P* =0.0077*	-0.235±0.278; *P* =0.3993
Nordic imbalance		-0.841±1.45; *P* =0.5641	-0.086±0.083; *P* =0.3069	-0.094±0.108; *P* =0.3843	-0.027±0.217; *P* =0.8979	-0.154±0.121; *P* =0.2018	0.086±0.16; *P*=0.5889
Scaled hip adduction (N·BW^{b-1})	^1.0839	3.982±1.65; *P* =0.0175*	0.175±0.094; *P* =0.0640	0.244±0.122; *P* =0.0475	0.557±0.247; *P* =0.0262*	0.285±0.136; *P* =0.0383*	0.236±0.181; *P* =01944
Hip adduction imbalance		1.29±1.69; *P* =0.4470	-0.114±0.080; *P* =0.1566	-0.078±0.104; *P* =0.4557	0.203±0.253; *P* =0.4254	0.224±0.116; *P* =0.0555	0.22±0.185; *P* =0.2365
Scaled hip abduction (N·BW^{b-1})	^1.4045	-14.705±17.22; *P* =0.3950	0.099±0.989; *P* =0.9198	-0.056±1.283; *P* =0.9653	-2.950±2.579; *P* =0.2550	-0.168±1.431; *P* =0.9066	-2.221±1.884; *P* =0.2409
Hip abduction imbalance		1.516±1.06; *P* =0.1578	0.111±0.059; *P* =0.0649	0.136±0.077; *P* =0.0794	0.069±0.159; *P* =0.6665	0.118±0.086: *P* =0.1707	-0.101±0.117; *P* =0.3899

*denotes significance at the level of *P* <0.05.
** denotes significance at the level of *P* <0.001.

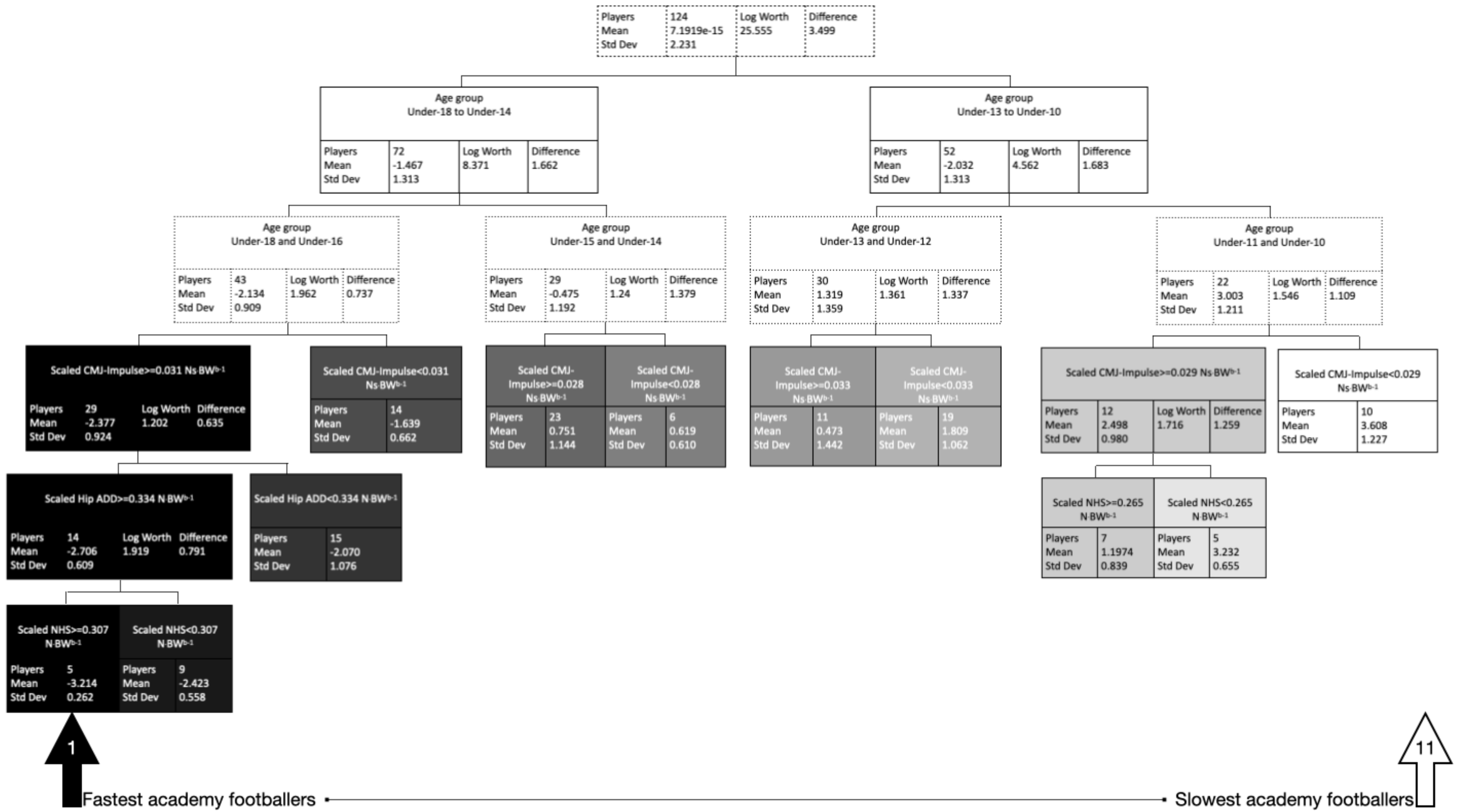

Figure 1 Decision tree induction analysis of field-based strength tests for the hip and groin provide insight into sprint and change of direction ability in 124 academy footballers (1 represents the fastest academy footballers and 11 characterises the slowest players).

Log strength score by log body weight provided the slope using the following equations:

Log Nordic strength = -1.322318 + 1.0873044*Log N BWT
Log Hip adduction = 1.245931 + 1.08389*Log N BWT
Log Hip abduction = -3.79351 + 1.404471*Log N BWT
Log Ns CMJ-jump impulse = -3.463775 + 1.3278736*Log N BWT

Supplementary material 1 Mean and absolute strength measures, imbalances, linear sprint and COD ability (mean ± SD) for 146 professional academy footballers.

Variable	N	Mean	Std Dev	Minimum	Maximum
Body weight (N)	146	546	151	247	851
Nordic hamstring strength (N)	146	257	90	100	473
Nordic hamstring strength imbalance (%)	146	4%	11%	-32%	27%
Hip abduction (N)	146	169	85	34	434
Hip abduction imbalance (%)	146	4%	16%	-34%	55%
Hip adduction (N)	146	276	109	80	555
Hip adduction imbalance (%)	146	3%	9%	-43%	43%
Jump impulse (Ns)	146	138	50	44	245
5m Best (s)	146	1.08	0.11	0.9	1.35
10m Best (s)	146	1.88	0.15	1.61	2.31
20m Best (s)	124	3.30	0.30	2.79	4.05
505 (mean) (s)	146	2.60	0.17	2.27	3.07
505 imbalance (%)	146	-1%	4%	-19%	19%
10m Flying Start (s)	124	1.41	0.19	0.94	2.29

N = Newtons; m = meters; s = seconds

Supplementary material 2 Correlation matrix for all (best) sprint (s) and (mean) COD (s) measures (range r = 0.64 to 0.92) in 146 professional academy youth soccer players.

Variable	5m Sprint (s)	10m Sprint (s)	20m Sprint (s)	505 Right (s)	505 Left (s)
5m Sprint (s)					
10m Sprint (s)	0.95				
20m Sprint (s)	0.86	0.90			
505 Right (s)	0.80	086	0.82		
505 Left (s)	0.74	0.79	0.79	0.86	
10m Flying Sprint (s)	0.64	0.66	0.92	0.65	0.65

s = seconds

Supplementary material 3 Loading Matrix for Principal Component Score

Variable	
5m Sprint (s)	0.92
10m Sprint (s)	0.95
20m Sprint (s)	0.97
505 Right (s)	0.92
505 Left (s)	0.88
10m Flying Sprint (s)	0.82

s = seconds