1. Title Page

Title: Strength, Power and Speed Characteristics in Elite Academy Soccer

Category of Manuscript: Original Scientific Research Study

Setting: Leicester City Football Club

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2. Bluf

The study's findings show age had a significant effect on certain physical characteristics, provide comparative data for elite academy soccer players for U16s, U18s and U23s age category, and show a relationship between measures of strength and sprint performance.

3. Abstract

The purpose of this study was 1) to present the strength, speed and power characteristic of elite youth soccer players and provide benchmark data for strength and conditioning coaches; 2) to compare the speed, strength and power characteristics of youth soccer players by competition structure age categories; and 3) to determine the relationships between lower-body strength, eccentric hamstring strength, upper-body strength, sprint and jump performance. Sixty-four (n = 64) academy male soccer players (U16s n = 18, U18s n = 22, and U23s n = 24), performed a predicted maximal squat test, bench press test and prone row test, eccentric hamstring strength test, countermovement jump, and 10m and 20m sprint speed test. The analysis of variance showed that age category had a significant effect on height, mass, countermovement jump, left eccentric hamstring strength, right eccentric hamstring strength, average eccentric hamstring strength, 20m sprint speed, estimated one repetition maximum squat absolute and relative, and estimated one repetition maximum bench press absolute. In the U16s age group, there was a significant relationship between 10m sprint and absolute squat strength (r = -0.759), and 20m sprint speed and absolute squat strength (r = -0.757). In the U23s age group, there was a significant relationship with 10m sprint speed and relative squat strength (r = -0.598), and 20m sprint speed and relative squat strength (r = -0.653). This study provides comparative data for elite academy soccer players. The benchmarks, allow strength and conditioning coaches to be individualised in their approach to training by creating subgroups.

Keywords: Football; Professional; testing; assessment; hamstrings

4. Text

A. INTRODUCTION

Soccer is an intermittent team sport that places high physiological demands on the aerobic and anaerobic energy systems and is becoming increasingly athletic in nature [1 and 2]. Evidence suggests that players who are stronger, faster, and more powerful, are at a competitive advantage [3 and 4]. Previous research has shown that greater lower-body strength may transfer to improvements in sprint performance [5 - 7] across several athlete populations, including soccer players [8 - 10]. This is likely since stronger athletes can develop higher peak ground reaction forces and impulse, which are strong determinants of sprint performance [11 – 13]. For these same reasons, stronger soccer players can also jump higher and may have a great opportunity to win more headers and tackles [14]. However, to the authors knowledge, there is limited research investigating the effect of strength, power, and speed, in elite academy soccer, specifically within the older age categories [e.g., Under 16 (U16) to U23] as other studies have tended to focus upon Under 16 players and below [15 - 19].

Despite the importance of strength, power, and speed for heightened match performance, there is a lack of research in elite academy soccer, especially when compared to elite academy rugby union [20] and rugby league [21]. The use of objective physical performance measures to support talent identification is an important consideration in optimizing the development of youth soccer players and assessing the strength and conditioning practices of sports clubs [21]. Understanding the physical characteristics of players by age category in the later stages of their academy development is important for practitioners as selection and deselection occurs within these age categories in order to identify potential first team players [20].

Research in elite academy rugby union has demonstrated that field-based measures of strength, power, and speed, develop across age categories [20]. This is supported by research in elite academy rugby league, where physical qualities have also been shown to differ between playing standards, with increased physical qualities related to higher playing levels and future career success [21]. It is not well understood whether these characteristics continue to increase with age category in elite academy soccer, which may have a greater technical skill component. As youth players progress up an academy pathway the increased training volumes, running distances and physical demands required to play in the older age categories increases the injury risk of young players [22]. Players with greater physical capacities such as speed, lower-body strength, repeat sprint ability and aerobic capacity can tolerate larger workloads and have a reduced injury risk [23]. Additional concerns may also present regarding the safety and reliability of common field-based techniques such as maximal strength testing in this cohort [24]. However, the one repetition maximum back squat has been shown to be a reliable and safe measure provided players have had 6-12 months' familiarisation with the exercise [25]. Despite previous research stating that there is a high perceived importance of increased eccentric hamstring strength as an important component for injury risk reduction in elite English soccer academies, there is a lack of data exploring eccentric hamstring strength in elite youth soccer [26]. This study provides novel data on eccentric hamstring strength in elite youth soccer.

This study has three purposes: 1) to present the speed, strength, and power characteristics of elite youth soccer players between the ages of 16 and 23 years, and provide benchmark data for strength and conditioning coaches; 2) to compare the speed, strength, and power characteristics of youth soccer players by competition structure age categories [i.e., U16, U18, U23] used within elite soccer academies; and 3) to determine the relationships within age categories between lower-body strength, eccentric hamstring strength, upper-body strength, sprint, and jump performance in academy soccer players. This research will assist strength and conditioning coaches in their understanding of the importance of strength, speed and power characteristics in youth soccer academy players, whilst providing comparative data which can be used for athlete benchmarking.

B. METHODS

Approach to the Problem:

Testing in this study took place during the competitive football season among 3 academy age groups. Countermovement jump and 10m and 20m sprint speed were performed to assess lower-body power and speed performance. Three repetition maximum (3RM) squat, bench press as well as prone row, and Nordic hamstring exercise were used to determine lower-body strength, upper-body pushing strength, upper-body pulling strength and eccentric hamstring strength respectively. Measures obtained were used to assess power, speed and strength characteristics and create benchmarks, to determine whether there were differences present between academy age groups, and to determine if any relationships between lower-body strength, eccentric hamstring strength, upper-body strength, sprint and jump performance exists.

Subjects:

A total of 64 male academy soccer players, U16s [n = 18, age = 15.65 ± 0.27 years, height = 172.0 ± 7.3 cm, body mass = 60.9 ± 8.6 kg], U18s [n = 22, 17.37 ± 0.63 years, 180.5 ± 8.3 cm, 73.8 ± 8.5 kg] and U23s [n = 24, 19.91 ± 1.14 years, 181.2 ± 7.9 cm, 78.9 ± 8.1 kg] were investigated in September of the 2017/2018 season, and all players trained at a Premier League Academy facility. Due to the nature of academy soccer, players regularly have to train with different age groups and also injuries occur, therefore all players were not able to complete the full testing battery. The U16s age category performed two gym and three to four field-based sessions per week, with one competitive fixture per week. The gym sessions focused on body weight competencies, technique development, resistance training education, and general strength development. Field sessions typically consisted of a 15-minute physical preparation block, focusing on preparing the players for the session ahead, while working on running mechanics, low-intensity plyometrics, and change of direction drills, followed by 75-90 minutes of soccer-based practice including technical drills, with games ranging in pitch sizes and player involvement. The U18s and U23s typically performed three gym and four field-based sessions alongside one to two games per week. Gym-based programmes focused on lower and upper-body strength, and full body power. Field sessions were similar to U16s. All experimental procedures were approved by the Derby University Ethics Committee. As all procedures were in line with day to day practices of the soccer club, a loco parentis form was signed by the Academy Manager.

Procedures:

Due to restrictions placed on this study by the competitive nature of academy football, all tests were performed over the course of the week to best align with the relevant teams playing and training schedules. This also meant that testing was conducted in a randomised order, however, all staff ensured players were well hydrated and able to perform maximally. All tests were undertaken by the lead researcher with the support of UKSCA accredited strength and conditioning coaches. All players were familiar with tests performed as they are part of the regular testing battery at the club.

Countermovement Jump (CMJ):

The CMJ was performed with hands positioned on the hips using an Optojump system (Micrograte, Italy). The Optojump system has been shown to demonstrate a strong concurrent validity [Intraclass correlation coefficient (ICC)=0.997-0.998] and excellent test-retest reliability [ICC=0.982-0.989, coefficient of variation (CV)=2.7%] for the estimation of CMJ height [27]. A standardized warm-up was performed prior to testing, which included dynamic movements involving bodyweight squats, followed by three practice CMJs at maximal intensity. Players were instructed to stand with feet shoulder width apart, flex their knees and hips to a self-selected depth, and then jump as high as possible ensuring legs remained fully extended during the flight phase of the jump. Players performed three attempts, with 30s rest allowed between trials and the highest jump was used for subsequent data analysis.

Sprint Speed:

Sprint speed was assessed over 10 m and 20 m using electronic timing gates [Brower Timing Systems, Utah, USA]. A standardized warm-up was performed prior to testing, which included jogging, dynamic movements, sprint mechanics drills, low-level plyometric drills and a gradual progression towards maximal sprinting. Players performed 2-3 practice trials ranging from 70-90% of their perceived maximum effort and were allowed 3-5 minutes' rest in between trials. Players were instructed to start 0.5 m behind the first timing gate and to sprint maximally in their own time past the 20 m timing gate. Times were recorded to the nearest 0.01 s with the quickest of the three times used for subsequent data analysis.

Strength:

A three repetition maximum (3RM) back squat, bench press, and prone row, were used as measures of lower-body, upper-body pushing, and pulling strength respectively. The nordic hamstring exercise (NHE) was used as a measure of eccentric hamstring strength. Due to being unfamiliar with the bench press and prone row exercises, the U16s did not undertake these tests. For all strength tests, a standardized warm-up was performed including dynamic stretches and movements, followed by a warm-up protocol of 2-4 sets of 3 reps, with self-selected increasing loads before attempting their 3RM with 3-5 minutes' rest between attempts.

A successful back squat was defined as the top of the player's thigh achieving a parallel alignment with the ground during the descent, which was visually determined by the lead researcher and accredited strength and conditioning coaches. For the bench press, a successful repetition was defined as the bar being lowered until it lightly touched the player's chest, and then returned to the start position with locked elbows. For the prone row, the bench height was prescribed so that the player's elbows were locked at the bottom position. Players then had to lift the bar until both sides contacted the bench. These methods for testing upper-body pushing and pulling strength have been well established in investigating strength characteristics in academy rugby disciplines [28]. The 3RM for all tests was determined based on either technical breakdown or a failure to lift a given weight for 3 reps, then the previous weight lifted was taken as the players 3RM. Baker's [29] 1RM predicted formula was used to convert data from 3RM scores, 3RM scores were multiplied by conversion factor 1.08 to predict an estimated 1RM. These scores were then divided by bodyweight to provide relative strength measures.

The NHE was performed using a NordBord device [Vald Performance, Version 1.0, Australia]. This device has shown high levels of test-retest reliability [ICC=0.83-0.90, CV=5.8-8.5%] [30]. Players were set up in the NordBord so that the handles were just above the lateral malleolus. Players were instructed to gradually lean forward at the slowest possible speed, thus maximally resisting dropping to the floor, while keeping the hands held across the chest and maintaining an anatomical straight line from shoulders to hips to knees throughout the movement [31]. A test was deemed acceptable when force output reached a distinct peak followed by a rapid decline in force, which occurred when athletes were no longer able to maximally resist dropping to the floor [31]. A test was violated if an athlete did not maintain an anatomical straight line from shoulders to hips to knees. The protocol consisted of one warm-up set with the players performing one repetition at their perceived 50%, 60%, and 70% maximum for the NHE. After a rest period of 3 minutes, players performed three repetitions with the maximal eccentric strength recorded from the 3 repetitions in the form of peak force [N]. Data is displayed for left leg [Ecc L], right leg [Ecc R], and an average of both legs [Ecc

AVG] for analysis by age category; for the determination of benchmarks, the average of both legs was used.

Statistical Analysis:

Data are presented as means ± standard deviations for each age category. Within-session reliability was determined retrospectively for 10m and 20m sprint speed and CMJ performance. CV values < 10% were considered acceptable and ICC values were interpreted as >0.9=excellent, 0.75-0.9=good, 0.5-0.75=moderate, and <0.5=poor [32]. To analyse the differences between age groups, a one-way analysis of variance [ANOVA] was conducted using SPSS [version 24.0] with an alpha level of $p < 0.05$. Tukey's post hoc analysis was completed to detect differences between age categories, where significant differences were found. Effect size calculations [Cohen's *d*] were used to determine the magnitude of difference that occurred between age groups and using Hopkins's effect size classification for determination of the magnitude of effect size trivial [0-0.19], small [0.2-0.59], moderate [0.60-1.19], large [1.20-2.0], and very large [>2.01] [33]. For variables where only U18s and U23s were tested, an independent *t*-Test was performed. Benchmarks were created using z-scores, for each physical variable. Relationships between lower-body strength, 10m and 20m sprint speed, and jump performance were determined using Pearson's correlations. Correlation coefficients were interpreted as being small [0.1], medium [0.3], large [0.5], very large [0.7], and extremely large [0.9] in line with previous recommendations [34]. While thresholds are available to interpret correlation coefficients, readers should note that 0.7 indicates that only 50 percent of variance is common and thus are advised to determine the strength of these relationshipsion light of this and what they deem to be practically meaningful.

C. RESULTS

Within-session retrospective reliability are shown in Table 1. All data showed acceptable CV values. ICC values are deemed to be moderate for U18s 20m sprint speed, CMJ jumps, and U23s 10m sprint speed, however considered in conjunction with the CV values the tests are deemed acceptable.

Table 2 shows the physical characteristics of elite academy soccer players by age category [U16s, U18s and U23s]. Table 3 also presents benchmarks by age category, and Table 4 presents the correlations between the strength, speed and power measures.

Speed, Strength and Power Differences

The ANOVA showed that age category had a significant effect on height [$p<0.001$], mass [$p<0.001$], CMJ [$p<0.001$], Ecc L [p = 0.019], Ecc R [$p<0.001$], Ecc AVG [p = 0.002], 20m sprint speed [$p<0.001$], estimated 1RM squat absolute [$p<0.001$] and relative squat [$p<0.001$], and estimated 1RM bench press absolute [p = 0.001].

Post hoc analysis revealed a moderate significant difference for height between U16s and U18s, and U16s and U23s, but not U18s and U23s. For weight, a large significant difference was seen between U16s and U18s and there was a very large significant difference between U16s and U23s. There was no significant difference between U18s and U23s, however, effect size analysis revealed a small practical difference.

For CMJ, there was a large significant difference between U16s and U23s, and U18s and U23s. There were no significant differences between age categories for 10m sprint speed. ES revealed a moderate difference between U16s and U23s, and U18s and U23s. For 20m sprint speed, there was a moderate significant difference between U16s and U18s, and a large significant difference between U16s and U23s. There was no significant difference between U18s and U23s, however, effect size analysis revealed a moderate practical difference.

For estimated 1RM squat absolute strength, there was a very large significant difference between U16s and U18s, and U16s and U23s, and no significant difference between U18s and U23s. These findings were the same for estimated 1RM squat relative strength. For Ecc AVG strength, there was a large significant difference between U16s and U18s, and U16s and U23s, and no significant difference between U18s and U23s. For estimated 1RM prone row absolute strength, there was no significant difference between U18s and U23s for absolute and relative strength. For estimated 1RM bench press absolute strength, there was a moderate significant difference between U18s and U23s, and no significant difference for relative strength.

Correlations

In the U16s, there was a large significant correlation between 10 m sprint speed and absolute estimated 1RM squat strength [$p<0.001, r$ = -0.759] and CMJ [$p<0.001, r$ = -0.832]. For 20 m sprint speed, there was a large significant correlation with absolute estimated 1RM squat strength [*p<0.001, r* = -0.757] and CMJ [*p<0.001, r* = -0.834]. There was also a large significant correlation between absolute estimated 1RM squat strength and CMJ [*p<0.05, r* = 0.656]. There were no significant correlations between eccentric hamstring strength and sprint and CMJ ability.

In the U18s, there was a large significant correlation between 10 m sprint speed and relative estimated 1RM squat strength [*p<0.05, r* = -0.621], CMJ [*p<0.05, r* = -0.511], and relative estimated 1RM prone row strength [p<0.05, r = -0.556]. For 20m sprint speed, there was a large significant correlation with absolute estimated 1RM squat strength [*p<0.05, r* = -0.579], CMJ [*p<0.001, r* = -0.640], and absolute estimated 1RM prone row strength [p<0.05, r = -0.585]. For CMJ, there was a large significant correlation with absolute estimated 1RM prone row strength [p<0.05, r = 0.515], and absolute estimated 1RM bench press strength [p<0.05, r = 0.583].

In the U23s, there was a large significant correlation between 10 m sprint speed and relative estimated 1RM squat strength [*p<0.001, r* = -0.598], and medium significant correlation with relative estimated 1RM bench press strength [p<0.05, r = -0.495]. For 20 m sprint, speed there was a large significant correlation with relative 1RM squat strength [*p<0.001, r* = -0.653], and relative estimated 1RM bench press strength [p<0.05, r = -0.528]. There was also a medium significant correlation between relative estimated 1RM squat strength and CMJ [*p<0.005, r* = 0.492].

Figures, Tables and Schemes

Table 1. Within-session Retrospective Reliability

	Sprints		**Jumps**
	10m	**20m**	**CMJ**
	U16s		
CV	1.16	0.65	2.17
ICC	0.763*	0.894*	0.978*
SEM	0.01	0.01	0.11
	U18s		
CV	0.65	0.47	2.73
ICC	0.764*	0.571*	0.571*
SEM	0.01	0.01	0.58
	U23s		
CV	1.44	0.90	3.05
ICC	0.611*	0.793*	0.877*
SEM	0.02	0.01	0.41

*p<0.05

Table 2. Physical Characteristics of Elite Academy Soccer Players by age categories.

	U16s (1)	*N*	U18s (2)	*N*	U23s (3)	*N*	T-Test (P-value)	ANOVA	Post Hoc	U16 vs U18 (Cohens d ± 95% CI)	U16 vs U23 (Cohens d ± 95% CI)	U18 vs U23 (Cohens d ± 95% CI)
Height (cm)	172.64 ± 7.34	*11*	180.46 ± 8.27	*22*	181.23 ± 7.94	*21*		p = 0.013	2,3 > 1	1.04 (0.63, 1.44)	1.16 (0.75, 1.58)	0.10 (0.02, 0.18)
Weight (kg)	60.90 ± 8.58	*11*	73.81 ± 8.50	*22*	78.89 ± 8.11	*22*		p = 0.000	2,3 >1	1.57 (1.09, 2.04)	2.23 (1.66, 2.80)	0.63 (0.52, 0.74)
CMJ (cm)	33.85 ± 4.65	*11*	36.56 ± 3.24	*18*	41.12 ± 4.47	*19*		p = 0.000	3 > 2,1	0.70 (0.36, 1.05)	1.66 (1.18, 2.13)	1.20 (0.96, 1.45)
Ecc L (N)	324.45 ± 65.13	*11*	382.76 ± 77.95	*17*	401.95 ± 69.74	*22*		p = 0.019	3 > 1	0.84 (0.50, 1.19)	1.19 (0.76, 1.61)	0.27 (0.07, 0.46)
Ecc R (N)	310.27 ± 48.28	*11*	401.47 ± 68.12	*17*	404.23 ± 62.47	*22*		p = 0.000	2,3 > 1	1.60 (1.14, 2.06)	1.74 (1.24, 2.23)	0.04 (-0.15, 0.23)
Ecc AVG (N)	317.45 ± 51.10	*11*	392.35 ± 70.06	*17*	403.27 ± 61.46	*22*		p = 0.002	2,3 > 1	1.26 (0.86,1.67)	1.57 (1.10, 2.04)	0.17 (-0.02, 0.36)
10m (s)	1.716 ± 0.059	*11*	1.704 ± 0.052	*16*	1.667 ± 0.070	*20*		p = 0.071	-	-0.22 (-0.50, 0.06)	-0.79 (-1.16, -0.42)	-0.63 (-0.85, -0.41)
20m (s)	3.038 ± 0.141	*11*	2.944 ± 0.081	*16*	2.873 ± 0.062	*20*		p = 0.000	2,3 > 1	-0.85 (-1.18, -0.51)	-1.59 (-2.05, -1.12)	-1.02 (-1.29, -0.75)
1RM* Squat (kg)	86.09 ± 11.03	*11*	131.19 ± 11.12	*16*	139.74 ± 14.09	*19*		p = 0.000	2,3 > 1	4.24 (3.25, 5.22)	4.39 (3.41, 5.37)	0.69 (0.48, 0.91)
1RM* Squat (kg/BW)	1.42 ± 0.14	*11*	1.81 ± 0.20	*16*	1.79 ± 0.22	*19*		p = 0.000	2,3 > 1	2.29 (1.71, 2.87)	2.11 (1.56, 2.66)	-0.05 (-0.22, 0.11)
1RM* Prone Row (kg)			78.35 ± 6.34	*20*	83.16 ± 10.15	*19*	p = 0.083					0.58 (0.52, 0.65)
1RM* Prone Row (kg/BW)			1.06 ± 0.12	*20*	1.06 ± 0.13	*19*	p = 0.879					-0.01 (-0.09, 0.08)
1RM* Bench Press (kg)			81.71 ± 8.47	*20*	93.81 ± 12.64	*19*	p = 0.001					1.15 (0.95, 1.36)
1RM* Bench Press (kg/BW)			1.12 ± 0.14	*20*	1.19 ± 0.18	*19*	p = 0.143					0.09 (0.01, 0.17)

Data presented as mean ± SD & Cohen's d effect size (90% confidence intervals). The number in parenthesis in the column headings relate to the number used for illustrating significant ($p<0.05$) difference in the post hoc analysis between age categories. *Estimated 1RM.

Table 3. Benchmarks of Physical Characteristics in Elite Academy Soccer Players by age categories.

Grading	Z-Score	CMJ (cm)	NHE (N)	10m (s)	20m (s)	1RM* Squat (kg)	1RM* Squat (%BW)	1RM* Prone Row (kg)	1RM* Prone Row (%BW)	1RM* Bench Press (kg)	1RM* Bench Press (%BW)
						U16s					
Poor	<-1.5	26 or less	243 or less	1.81 or more	3.25 or more	69 or less	1.21 or less				
Below Average	-1.5 to -0.5	27 - 31	244 - 292	1.76 - 1.80	3.12 - 3.24	70 - 80	1.22 – 1.34				
Average	-0.5 to 0.5	32 - 36	293 - 341	1.69 - 1.75	2.97 - 3.11	81 - 91	1.35 – 1.49				
Good	0.5 to 1.5	37 - 41	342 – 390	1.64 - 1.68	2.84 - 2.96	92 - 102	1.50 – 1.62				
Excellent	>1.5	42 or more	390 or more	1.63 or less	2.83 or less	103 or more	1.63 or more				
						U18s					
Poor	<-1.5	31 or less	289 or less	1.79 or more	3.07 or more	114 or less	1.50 or less	68 or less	0.87 or less	69 or less	0.90 or less
Below Average	-1.5 to -0.5	32 - 34	290 – 357	1.74 - 1.78	2.99 - 3.06	115 - 125	1.51 – 1.70	69 - 74	0.88 – 0.99	70 - 77	0.92 – 1.04
Average	-0.5 to 0.5	35 - 39	358 – 426	1.67 - 1.73	2.90 - 2.98	126 - 136	1.71 – 1.91	75 - 81	1.00 – 1.12	78 - 86	1.05 – 1.19
Good	0.5 to 1.5	40 - 42	427 – 494	1.62 - 1.66	2.82 - 2.89	137 - 147	1.92 – 2.11	82 - 87	1.13 – 1.24	87 - 94	1.20 – 1.32
Excellent	>1.5	43 or more	495 or more	1.61 or less	2.81 or less	148 or more	2.12 or more	88 or more	1.25 or more	95 or more	1.33 or more
						U23s					
Poor	<-1.5	35 or less	312 or less	1.78 or more	2.97 or more	118 or less	1.46 or less	67 or less	0.85 or less	74 or less	0.91 or less
Below Average	-1.5 to -0.5	36 - 39	313 – 372	1.71 - 1.77	2.91 - 2.96	119 - 132	1.47 – 1.67	68 - 77	0.86 – 0.98	75 - 87	0.92 – 1.09
Average	-0.5 to 0.5	40 - 43	373 – 433	1.64 - 1.70	2.84 - 2.90	133 - 147	1.68 – 1.90	78 - 88	0.99 – 1.13	88 - 100	1.10 – 1.28
Good	0.5 to 1.5	44 - 47	434 – 493	1.57 - 1.63	2.78 - 2.83	148 - 161	1.91 – 2.11	89 - 98	1.14 – 1.26	101 - 113	1.29 – 1.46
Excellent	>1.5	48 or more	494 or more	1.56 or less	2.77 or less	162 or more	2.12 or more	99 or more	1.27	114 or more	1.47 or more

*Estimated 1RM.

Table 4. Relationships (Pearson's correlations, r) between estimated 1RM squat strength, sprints and CMJ.

	Power	Squat		Ecc Avg	Bench Press		Prone Row	
U16s								
	Power	**Squat**		**Ecc Avg**	**Bench Press**		**Prone Row**	
	CMJ	Absolute	Relative		Absolute	Relative	Absolute	Relative
10m	-0.832**	-0.759**	-0.122	0.085				
20m	-0.834**	-0.757**	-0.013	0.142				
CMJ		0.656*	0.022	0.258				
U18s								
	Power	**Squat**		**Ecc Avg**	**Bench Press**		**Prone Row**	
	CMJ	Absolute	Relative		Absolute	Relative	Absolute	Relative
10m	-0.511*	-0.418	-0.621*	0.311	-0.114	-0.487	-0.462	-0.556*
20m	-0.640**	-0.579*	-0.270	-0.34	-0.483	-.308	-0.585*	-0.226
CMJ		0.359	0.064	0.042	0.515*	0.424	0.583*	0.354
U23s								
	Power	**Squat**		**Ecc Avg**	**Bench Press**		**Prone Row**	
	CMJ	Absolute	Relative		Absolute	Relative	Absolute	Relative
10m	-0.216	-0.072	-0.598**	0.085	-0.059	-0.495*	0.241	-0.387
20m	-0.379	-0.268	-0.653**	0.142	-0.151	-0.528*	0.084	-0.454
CMJ		0.286	0.492*	-0.029	-0.239	0.078	-0.021	0.308

**p<0.001

*p<0.05

D. DISCUSSION

The aims of this study were to 1) present the speed, strength and power characteristics in elite academy soccer players from U16s to U23s; 2) compare speed, strength and power characteristics by competition structure age categories; and 3) evaluate relationships between strength, power and speed characteristics. Age had a significant effect on height, body mass, CMJ, 20 m sprint speed, eccentric hamstring strength, estimated 1RM bench press absolute measures, and estimated 1RM squat absolute and relative measures. In the U16 age category, absolute lower-body strength was highly correlated with sprint speed performance, and at the U23 age category, relative lower-body strength was highly correlated with sprint speed performance.

Minimal differences in height and body mass were observed post the U18 age category as expected due to the normal trajectory of growth and maturation, reflecting that most players will have approached adult height [35]. Interestingly, research in rugby league has shown that weight can be expected to increase further into the older age categories [35]; however, this trend does not appear to be supported here in academy soccer. Potentially, unlike rugby where momentum generates an important component to performance, soccer is more concerned with maintaining an appropriate power to weight ratio. No significant difference was observed for CMJ between U16s and U18s. This may be related to the significant increase in body mass as player's progress to the U18s, associated with peak weight velocity occurring after peak height velocity [36], and may highlight the need to express CMJ performance metrics relative to body mass.

The 10m sprint results support previous research in academy rugby league and union, where there was no significant increase in speed in the older age categories for 10 m and 20 m sprint speed [over 16 years old] [20 and 35]. Similar to CMJ testing as discussed above, gains in body mass and smaller changes in height may decrease speed development, however, if body mass has increased and players are running at the same speed, momentum has increased which may be more effective for game based speed during offensive and defensive duels in soccer. This suggests that the inclusion of body mass into speed monitoring through the assessment of momentum [body mass * velocity], may be an important consideration for evaluating players past the age of 16 [21]. As there was a significant difference in

20m sprint speed between age categories but none at 10m, one cannot conclude whether accelerative capacities are hindered with growth and maturation [or not appropriately trained], and thus require additional training during adolescence. However, when examining effect sizes, there was a small to moderate increase in sprint speed across age categories, and with the increases in momentum present as players got heavier, experiencing small to moderate increases in sprint speed could imply players sprinting ability did increase with age throughout the academy structure.

Lower-body strength is an important physical characteristic that underpins a range of other athletic performance aspects, such as power production and injury prevention in team sport athletes [10 and 37]. There is limited data on estimated 1RM back squat strength for U16s and U23s in elite academy soccer. This study reports that U16s – U23s can be safely and effectively tested using a 3RM protocol, provided athletes have 6-12 months' familiarisation. There was no significant increase in estimated 1RM squat absolute and relative strength scores past the U18 age category, but a moderate effect size was present between absolute scores. Increases in strength between U16s and U18s can be explained through increases in volume of strength training alongside increases in body mass. The lack of significant difference between U18s and U23s may be due to the increasingly competitive fixture list associated with U23s, causing a shift in focus from physical development to match preparation. Thus specific training interventions have switched focus from developing strength to maintaining strength, while ensuring optimal match and training availability.

Hamstring strains are one of the most common injury types in several sports [38-40] including soccer, and have high rates of recurrence [30]. Previous research has reported low eccentric hamstring strength as a risk factor for future hamstring injury [41 and 42]. Similar to relative back squat strength scores, there was no significant increase in eccentric hamstring strength past the U18 age group. Increases in strength between the U16s and U18s can again be explained by continued participation in a structured strength training programme, the natural processes of growth and maturation, increases in body mass, and increases in limb length which will enhance joint torque capabilities; the lack of increase between U18s and U23s is perhaps due to the shift in training focus. Previous research in Elite Australian Football [n = 210, age = 23.3 ± 3.7 years] demonstrated that eccentric hamstring strength below 265N at the start of preseason and 279N at the end of preseason increased the risk of future hamstring strain injury 2.7 fold [$p = 0.006$] and 4.3 fold [$p = 0.002$] respectively [43]. This highlights promising results from the tests performed in this study, as the majority of all age categories were above this threshold. Caution should be advised when interpreting these results, as the study into Elite Australian Football determined eccentric hamstring strength as an average of the peak forces from the 3 repetitions, this study determined eccentric hamstring strength from the highest value from the 3 repetitions.

For upper-body strength scores, there was no significant difference in relative measures between U18s and U23s. As above this may be due to a shift in training focus as player's progress up the academy age groups, and as soccer isn't a collision sport, upper-body strength may not be as an important a factor in match play than other sports. Till [35] found similar results in rugby league with no significant difference between relative measures, highlight how in other sports a shift in training focus may also occur as players near the professional level.

In accordance with previous research, the current study found strong relationships with lower-body strength, and sprint and CMJ performance [5, 7, 10 and 44]. In the U16s, there was a significant correlation between absolute estimated 1RM squat strength and sprint speed and CMJ. Interestingly, as the age groups get older and subsequently heavier, sprint speed appears to be more related to relative estimated 1RM squat strength [see Table 4]. In the U18s, there was a significant correlation between 10m sprint speed and relative squat strength, and 20m sprint speed and absolute squat strength. In the U23s, there was a significant relationship between relative squat strength and sprint speed, and CMJ. No relationships were observed in this age group between absolute squat strength and any other physical performance measure. There are clear neural discrepancies between young and older athletes, whereby a higher ability for voluntary muscle activation is present with advances in chronological age, in addition to lower antagonistic coactivation, higher rate of force development, and shorter electromechanical delay than youth/ children [45]. Therefore, U16s potentially do not have the neural capabilities to maximise the amount of relative force they can produce, hence why those who can produce the highest absolute force are quickest and jump highest. U16s may still be in a strength deficit phase as highlighted by Suchomel [46], which suggests that even though relative strength is improving, athletes may not be able to exploit their levels of strength and transfer them into performance benefits in their sport [46]. Hence, the significant correlation with absolute strength and sprint speed. The U23s may be present in the strength association phase or in the strength reserve phase, which shows high levels of relative strength to correlate with performance capability [46]. Adaptations associated with the strength association phase include increases in motor unit rate coding, neural drive, inter and intra-muscular coordination, motor unit synchronization, ability to use the stretch-shortening cycle, and decreases in the neural inhibitory processes [46]. There was a large jump in body mass and squat strength between U16s and U18s, which then slowed between U18s and U23s. Therefore, in younger athletes where mass is lower, relative strength is less of a factor compared to the older heavier ages, where relative strength is more important due to the need to apply greater force in which to change their state of momentum. There was no significant correlation between eccentric hamstring strength and sprint speed in any of the age groups. This may be expected as the gluteus muscles act as the primary hip extensors in early acceleration performance [47]. As the body reaches a more overall vertical position and higher sprint velocities [>7ms^2] are reached the hamstrings play a more important component in hip extension/ knee flexion [47]. Previous research [47], has shown the importance of eccentric hamstring strength in horizontal force production in sprint acceleration, but sprints performed were 6s in duration, the 20m sprints performed in this study were on average less than half of this. Further showing how, as sprint distance increases the importance of the hamstrings increases also.

Benchmarking strength characteristics is a process widely used in the practical environment, with many clubs and governing organizations of the league creating their own categorisations. Limited research has been performed on benchmarks, and therefore there is a lack of data on how to effectively establish these and implement them. Subgroups can be created as a result of the benchmarks, and gym sessions individualized to focus on areas players are weak in.

With regards to limitations, this study only investigated one soccer club. Therefore, the results of this may be affected by the training and recruitment strategies of this club, as well as the number of players (sample size) that could be tested. Future research is therefore needed to determine the applicability of these results to other similar clubs and players. Finally, due to the demanding fixture and training schedule in elite youth soccer, tests had to be completed over the course of the week rather than on defined testing days. This may have affected the results of the study, but also provides practically applicable results as other academies may test in this manner due to similar constraints.

E. PRACTICAL APPLICATIONS

The study's findings provide comparative data for elite academy soccer players for U16s, U18s and U23s age category. The creation of benchmarks, allow strength and conditioning coaches to individualise their approach to training by creating subgroups. This study shows that physical capacities such as strength are related to sprint speed in elite academy soccer players. This study also further shows the neural discrepancies between U16 and U23 athletes, as in U16 ages groups, a relationship between absolute squat strength and sprint speed was observed, and in U23 groups, a relationship between relative squat strength and sprint speed was observed. As the U16 age groups do not have the neural capabilities to maximise the amount of relative force they can produce, targeting general strength capacities should be the focus and result in improvements in both sprint and jump performances. Specific means of training to increase strength relative to body mass and to enabling athletes to exploit their level of strength should be used with U23 athletes, which should result in improvements in sprint and jump performances.

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References

1. Morgans, R.; Orme, P.; Anderson, L.; Drust, B. Principles and practices of training for soccer. **Journal of Sport and Health Science.** 3(4), pp. 251-257. 2014.
2. Barnes, C., Archer, D.T., Hogg, B., Bush, M. and Bradley, P.S. The evolution of physical and technical performance parameters in the English Premier League. **International journal of sports medicine**. 35(13), pp.1095-1100. 2014.
3. Chelly, M.S.; Fathloun, M.; Cherif, N.; Amar, M.B.; Tabka, Z.; Van Praagh, E. Effects of a back squat training program on leg power, jump, and sprint performances in junior soccer players. **The Journal of Strength and Conditioning Research.** 23(8), pp. 2241-2249. 2009.

4. Turner, A.; Stewart, P. Strength and Conditioning for Soccer Players. **Strength and Conditioning Journal.** 36(4), pp. 1-13. 2014.
5. Seitz, L.B.; Reyes, A.; Tran, T.T.; De Villarreal, E.S.; Haff, G.G. Increases in lower-body strength transfer positively to sprint performance: a systematic review with meta-analysis. **Sports Medicine.** 44(12), pp. 1693-1702. 2014.
6. McBride, J.M., Blow, D., Kirby, T.J., Haines, T.L., Dayne, A.M. and Triplett, N.T. Relationship between maximal squat strength and five, ten, and forty yard sprint times. **The Journal of Strength and Conditioning Research.** 23(6), pp. 1633-1636. 2009.
7. Meir, R.; Newton, R.; Curtis, E.; Fardell, M.; Butler, B. Physical fitness qualities of professional rugby league football players: determination of positional differences. **The Journal of Strength and Conditioning Research.** 15(4), pp. 450-458. 2001.
8. Comfort, P.; Stewart, A.; Bloom, L.; Clarkson, B. Relationships between strength, sprint, and jump performance in well-trained youth soccer players. **The Journal of Strength and Conditioning Research.** 28(1), pp. 173-177. 2014.
9. Styles, W.J.; Matthews, M.J.; Comfort, P. Effects of strength training on squat and sprint performance in soccer players. **The Journal of Strength and Conditioning Research.** 30(6), pp. 1534-1539. 2016.
10. Wisløff, U.; Castagna, C.; Helgerud, J.; Jones, R.; Hoff, J. Strong correlation of maximal squat strength with sprint performance and vertical jump height in elite soccer players. **British Journal of Sports Medicine.** 38(3), pp. 285-288. 2004.
11. Cronin, J.B.; Hansen, K.T. Strength and power predictors of sports speed. **The Journal of Strength and Conditioning Research.** 19(2), pp.349. 2005.
12. Weyand, P.G.; Lin, J.E.; Bundle, M.W. Sprint performance-duration relationships are set by the fractional duration of external force application. **American Journal of Physiology-Regulatory, Integrative and Comparative Physiology.** 290(3), pp. R758-R765. 2006.
13. Weyand, P.G.; Sandell, R.F.; Prime, D.N.; Bundle, M.W. The biological limits to running speed are imposed from the ground up. **Journal of Applied Physiology.** 108(4), pp.950-961. 2010.

14. Wing, C.; Bishop, C.; Turner, A. The importance of strength and power on key performance indicators in elite youth soccer. **The Journal of Strength and Conditioning Research.** 2018.
15. Williams, C.A.; Oliver, J.L.; Faulkner, J. Seasonal monitoring of sprint and jump performance in a soccer youth academy. **International Journal of Sports Physiology and Performance.** 6(2), pp. 264-275. 2011.
16. Morris, R.; Emmonds, S.; Jones, B.; Myers, T.D.; Clarke, N.D.; Lake, J.; Ellis, M.; Singleton, D.; Roe, G.; Till, K. Seasonal changes in physical qualities of elite youth soccer players according to maturity status: comparisons with aged matched controls. **Science and Medicine in Football.** Pp. 1-9. 2018.
17. Peñailillo, L.; Espíldora, F.; Jannas-Vela, S.; Mujika, I.; Zbinden-Foncea, H. Muscle strength and speed performance in youth soccer players. **Journal of Human Kinetics.** 50(1), pp. 203-210. 2016.
18. Emmonds, S.; Till, K.; Jones, B.; Mellis, M.; Pears, M. Anthropometric, speed and endurance characteristics of English academy soccer players: Do they influence obtaining a professional contract at 18 years of age? **International Journal of Sports Science and Coaching.** 11(2), pp.212-218. 2016.
19. 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. **Journal of Science and Medicine in Sport.** 13(1), pp. 90-95. 2010.
20. Darrall-Jones, J.D.; Jones, B.; Till, K. Anthropometric and physical profiles of English academy rugby union players. **The Journal of Strength and Conditioning Research.** 29(8), pp. 2086-2096. 2015.
21. Till, K.; Scantlebury, S.; Jones, B. Anthropometric and Physical Qualities of Elite Male Youth Rugby League Players. **Sports Medicine**. Pp. 1-16. 2017.
22. Mooney, T.; Malone, S.; Cullen, B.D.; Darragh, I.; Bennett, S.; Collins, K.; Price, P.; Patterson, S. Investigating the role of anthropometric and physical performance measures on team selection in elite and sub-elite under-20 gaelic football players. **Journal of Australian Strength and Conditioning.** 2019

23. Malone, S.; Hughes, B.; Doran, D.A.; Collins, K.; Gabbett, T.J. Can the workload–injury relationship be moderated by improved strength, speed and repeated-sprint qualities? **Journal of Science and Medicine in Sport.** 22(1), pp. 29-34. 2019.
24. Haycraft, J.A.; Kovalchik, S.; Pyne, D.B.; Robertson, S. Physical characteristics of players within the Australian FootballSoccer League participation pathways: a systematic review. **Sports Medicine.** 3(1), pp. 46. 2017.
25. Comfort, P.; McMahon, J.J. Reliability of maximal back squat and power clean performances in inexperienced athletes. **The Journal of Strength and Conditioning Research.** 29(11), pp. 3089-3096. 2015.
26. Read, P.J.; Jimenez, P.; Oliver, J.L.; Lloyd, R.S. Injury prevention in male youth soccer: Current practices and perceptions of practitioners working at elite English academies. **Journal of Sports Science.** 36(12), pp. 1423-1431. 2018.
27. Glatthorn, J.F.; Gouge, S.; Nussbaumer, S.; Stauffacher, S.; Impellizzeri, F.M.; Maffiuletti, N.A. Validity and reliability of Optojump photoelectric cells for estimating vertical jump height. **The Journal of Strength and Conditioning Research.** 25(2), pp. 556-560. 2011.
28. Till, K.; Jones, B.; Emmonds, S.; Tester, E.; Fahey, J.; Cooke, C. Seasonal changes in anthropometric and physical characteristics within English academy rugby league players. **The Journal of Strength and Conditioning Research.** 28(9), pp. 2689-2696. 2014.
29. Baker, D. Predicting 1RM or submaximal strength levels from simple reps to fatigue (RTF) tests. **Strength and Conditioning Coach.** 12(4), pp. 19-24. 2004.
30. Opar, D.A.; Piatkowski, T.; Williams, M.D.; Shield, A.J. A novel device using the Nordic hamstring exercise to assess eccentric knee flexor strength: a reliability and retrospective injury study. **Journal Orthopedic and Sports Physical Therapy.** 43(9), pp. 636-640. 2013.
31. Buchheit, M.; Cholley, Y.; Nagel, M.; Poulos, N. The effect of body mass on eccentric knee-flexor strength assessed with an instrumented Nordic hamstring device (Nordbord) in football players. **International Journal of Sports Physiology and Performance.** 11(6), pp. 721-726. 2016.

32. Bishop, C., Pereira, L.A., Reis, V.P., Read, P., Turner, A.N. and Loturco, I. Comparing the magnitude and direction of asymmetry during the squat, countermovement and drop jump tests in elite youth female soccer players. **Journal of Sports Sciences**. Pp.1-8. 2019.
33. Flanagan, E.P. The effect size statistic—Applications for the strength and conditioning coach. **Strength & Conditioning Journal.** 35(5), pp.37-40. 2013.
34. Turner, A.; Brazier, J.; Bishop, C.; Chavda, S.; Cree, J.; Read, P. Data analysis for strength and conditioning coaches: Using excel to analyze reliability, differences, and relationships. **Strength and Conditioning Journal.** *37(1),* pp. 76-83. 2015.
35. Till, K.; Tester, E.; Jones, B.; Emmonds, S.; Fahey, J.; Cooke, C. Anthropometric and physical characteristics of English academy rugby league players. **The Journal of Strength and Conditioning Research.** *28(2),* pp. 319-327. 2014.
36. Lloyd, R.S.; Oliver, J.L. The youth physical development model: A new approach to long-term athletic development. **Strength and Conditioning Journal.** 34(3), pp. 61-72. 2012.
37. Nibali, M.L.; Chapman, D.W.; Robergs, R.A.; Drinkwater, E.J. A rationale for assessing the lower-body power profile in team sport athletes. **The Journal of Strength and Conditioning Research.** 27(2), pp. 388-397. 2013.
38. Brooks, J.H.; Fuller, C.W.; Kemp, S.P.; Reddin, D.B. Incidence, risk, and prevention of hamstring muscle injuries in professional rugby union. **The American Journal of Sports Medicine.** 34(8), pp. 1297-1306. 2006.
39. Ekstrand, J.; Hägglund, M.; Waldén, M. Injury incidence and injury patterns in professional footballsoccer-the UEFA injury study. **British Journal of Sports Medicine.** 2009.
40. Orchard, J.; Seward, H. AFL injury report: season 2007. **Sport Health.** 26(2), p. 23. 2008.
41. Croisier, J.L.; Ganteaume, S.; Binet, J.; Genty, M. Ferret, J.M. Strength imbalances and prevention of hamstring injury in professional soccer players: a prospective study. **The American Journal of Sports Medicine.** 36(8), pp. 1469-1475. 2008.
42. Sugiura, Y.; Saito, T.; Sakuraba, K.; Sakuma, K.; Suzuki, E. Strength deficits identified with concentric action of the hip extensors and eccentric action of the hamstrings predispose to

hamstring injury in elite sprinters. **Journal Orthopedic and Sports Physical Therapy.** 38(8), pp. 457-464. 2008.

43. Opar, D.A.; Williams, M.; Timmins, R.; Hickey, J.; Duhig, S.; Shield, A. Eccentric hamstring strength and hamstring injury risk in Australian footballers. **Medicine and Science in Sports and Exercise.** 47(4), pp. 857-865. 2014.
44. Comfort, P.; Bullock, N.; Pearson, S.J. A comparison of maximal squat strength and 5-, 10-, and 20-meter sprint times, in athletes and recreationally trained men. **The Journal of Strength and Conditioning Research.** 26(4), pp. 937-940. 2012.
45. Legerlotz, K., Marzilger, R., Bohm, S. and Arampatzis, A., 2016. Physiological adaptations following resistance training in youth athletes—a narrative review. **Pediatric Exercise Science.** *28*(4), pp.501-520. 2016.
46. Suchomel, T.J., Nimphius, S. and Stone, M.H., 2016. The importance of muscular strength in athletic performance. **Sports Medicine.** *46*(10), pp.1419-1449. 2016.
47. Morin, J.B., Gimenez, P., Edouard, P., Arnal, P., Jiménez-Reyes, P., Samozino, P., Brughelli, M. and Mendiguchia, J. Sprint acceleration mechanics: the major role of hamstrings in horizontal force production. **Frontiers in Physiology.** *6*, p.404. 2015.