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ABSTRACT

We aimed to determine key biomechanical parameters explaining age-related jumping performance differences in youth elite female soccer players. Multiple biomechanical parameters from counter-movement (CMJ) squat (SJ) and drop (DJ) jump testing of elite female soccer players (n = 60) within the same national training centre were analysed across ages 9-11y, 12-14y and 15-19y. Effects of age group and jump type on jump height were found, with the older jumping higher than the younger groups in all jumps (P < 0.05). For DJ, higher reactive strength index was found for older, compared to each younger group (P < 0.001). For CMJ and SJ, peak power was the most decisive characteristic, with significant differences between each group for absolute peak power (P < 0.0001) and body-weight-normalised peak power in CMJ (57 ± 7W/kg, 50 ± 7W/kg, 44.7 ± 5.5W/kg; P < 0.05) and between the older and each younger group in SJ (56.7 ± 7.1W/kg, 48.9 ± 7.1W/kg, 44.6 ± 6W/kg; P < 0.01). Age-related differences in jumping performance in youth elite female soccer players appear to be due to power production during standing jumps and by the ability to jump with shorter ground contact times during reactive jumps.

Introduction

Soccer is a high-intensity field sport that requires explosive movements, such as sprinting, jumping, kicking and changing direction (Svensson & Drust, 2005). These explosive actions related to soccer performance involve high muscular forces, high rates of force development (RFD) and power output (Haugen, Tonnessen, & Seiler, 2012; Silva, Nassis, & Rebelo, 2015). While the quality of a player cannot be determined by a single performance parameter, insight into speed and power characteristics is needed to further our understanding of the biomechanical mechanisms behind these performance parameters and to optimise player development and talent identification (Silva et al., 2015; Vescovi, Rupf, Brown, & Marques, 2011).

The need to investigate anaerobic performance parameters is present in both male and female youth soccer players. Females show significantly lower absolute strength, power, RFD, muscle-tendon unit stiffness, sprinting speed, agility, jump height and maximal oxygen uptake compared to males (Hannah, Minshull, Buckthorpe, & Folland, 2012; Helgerud, Hoff, & Wisløff, 2002; Mujika, Santisteban, Impellizzeri, & Castagna, 2009; Stolen, Chamari, Castagna, & Wisloff, 2005; Van Praagh & Dore, 2002). Female athletes also show different age-related improvements in anaerobic performance, with peaks at different ages compared to male athletes (Svensson & Drust, 2005; Vincent & Glamser, 2006). This supports the idea that different outcomes can be expected, and different standards can be set

for elite female soccer players compared to elite male soccer players, which has important implications for the physical training and testing of female versus male players, in particular during maturation. However, there is comparatively much less research available examining physical performance characteristics of developing female soccer players, compared to developing male soccer players, despite women's soccer becoming increasingly popular both at recreational and professional levels.

Jumping performance is correlated with other anaerobic performance characteristics in soccer, such as sprinting and changing direction (Vescovi & McGuigan, 2008). Multiple studies in both male and female soccer players (Cometti, Maffiuletti, Pousson, Chatard, & Maffulli, 2001; Mujika et al., 2009; Ramos-Campo, Rubio-Arias, Carrasco-Poyatos, & Alcaraz, 2016; Reilly, Williams, Nevill, & Franks, 2000; Silva et al., 2015; Smith et al., 2007; Vescovi et al., 2011) have shown that elite soccer players and first team players perform better on jumping tests compared with sub-elite players and reserve players. Different jumping tests are used to provide insight into the speed and power characteristics of a player. The countermovement jump (CMJ), squat jump (SJ) and the drop jump (DJ) are three of the most commonly used jumping tests in elite sports performance literature (Gissis et al., 2006; Castagna & Castellini, 2013; Sheppard, Nolan, & Newton, 2012). The CMJ has distinguished between different levels of female soccer performance multiple times (Castagna & Castellini, 2013; Haugen et al., 2012;

Hoare & Warr, 2000; Ramos-Campo et al., 2016; Smith et al., 2007; Vescovi & McGuigan, 2008; Vescovi et al., 2011). CMJ has also been used to examine differences in jumping performance across multiple age groups in female soccer players (Castagna & Castellini, 2013; Haugen et al., 2012; Manson, Brughelli, & Harris, 2014; Mujika et al., 2009; Vescovi & McGuigan, 2008; Vescovi et al., 2011), where older players jump significantly higher than younger players (Castagna & Castellini, 2013; Haugen et al., 2012; Manson et al., 2014; Vescovi et al., 2011). However, analysing jumping performance with one test in iso-lation limits the extent to which a deeper understanding of the underlying physiological and biomechanical characteristics can be gained. By analysing different jumps that rely on specific jumping mechanisms (i.e. stretch-shortening cycle, reactive strength), more insight into overall physical performance could be gained. To this end, Castagna and Castellini (2013) examined SJ performance, in addition to CMJ performance, across different age groups in female soccer players and again showed an age difference between their under-19 players and under-17 players in both CMJ and SJ. According to Castagna and Castellini (2013) these performance differ-ences provide evidence for a less developed stretch-shortening cycle (SSC) efficiency in younger players compared to older players. The SSC is suggested to be an important sports performance characteristic (Sheppard et al., 2008). Going even further, however, we could argue that the addition of the DJ, with a reactive ground contact phase would add an additional task requirement not covered in the CMJ and SJ. Assessing multiple jumps in this way and interpreting the differences between these jumps and their associated parameters together is potentially necessary to obtain more relevant information for soccer training, testing and talent identification.

The present retrospective study aimed to determine key biomechanical parameters explaining age-related jumping per-formance differences in youth elite female soccer players. To this end, we analysed performance data from CMJ, SJ and DJ testing of youth elite female soccer players within the same national training centre and training programme in the Netherlands, thereby avoiding limitations related to differences in teams or training programmes.

Methods

Study design

In this study, a retrospective analysis of CMJ, SJ and DJ test data collected as part of the regular performance testing in the national female soccer training programme was conducted. All testing was done on the same day, in-season, preceding the training programme's winter break. Datasets from indivi-duals were extracted from the training programme's database for analysis when (i) data from the jumping tests were collected on the same day at the midpoint of the season, (ii) data for all three jumping tests were available, and (iii) the age, height and weight of the players were recorded at the date of testing and were available in the database. The study protocol was regis-tered with the medical ethics committee of Maastricht University (number: 2017-0282; METC azM/UM) in accordance with Dutch law.

Training programme and players

At the time of data extraction, the training programme included 74 elite female soccer players between 9 and 19 years old, divided across three age-dictated training groups: age group 15–19 (n = 26), age group 12–14 (n = 23) and age group 9–11 (n = 25). Pubertal status data was not available in the database and was not feasible to obtain in the current project, so these age groups were also used for analysis in this study, which provided a division based on age and training programme. All players participate in high-level male division leagues in their own age categories and train four to six times per week, with increasing intensity, frequency and duration through the age groups. All players compete regularly in national tournaments and activities, with the majority also competing in international tournaments in their age category.

Procedures

The three tests of jumping performance are regularly con-ducted with a standardised protocol by the strength & condi-tioning coach of the training programme. Players performed a standardised warm-up with different activating and mobilis-ing exercises following the RAMP protocol (Jeffreys, 2007). Thereafter, players performed two to three repetitions of each jump at a submaximal level. For the testing itself, two attempts of CMJ, SJ and DJ were performed with a 30-second recovery in between repetitions of the same jump and a two-minute rest between the different jumps, regulated with a handheld stop-watch. All tests were conducted in the same environmental conditions with the strength and conditioning coach of the programme. No encouragement, motivation nor feedback were given by the strength and conditioning coach except for information about the resting time. No physical training was performed in the 24h prior to testing.

Data collection and analysis

Jumping performance for CMJ and SJ was measured with the FT700 Power Cage (Ballistic Measurement System; Fitness Technology, Australia, 2015), including a force plate and cable transducer (600Hz) and DJ performance was measured with the Swift Speedmat (switch-based system; Swift Performance, Australia, 2017) for the DJ. During all three jumps, a wooden stick was held at the back of the shoulders to restrict arm movement. The cable connected to the cable transducer of the Power Cage was attached to the stick. During CMJ testing, players were asked to stand still for three seconds, then jump as high as possible using their perceived necessary countermove-ment. During SJ testing, players were asked to stand still for three seconds in a squat position with a 90° knee angle and thereafter jump as high as possible with no countermovement permitted. The use of countermovement was verified by the strength and conditioning coach of the programme, with assis-tance of a video camera. During DJ testing, players stepped off a 30cm high box and jumped as high as possible with ground contact time as short as possible. Jumping instead of stepping off the box and a knee flexion bigger than 20° was not

permitted and was verified by the strength and conditioning coach.

Jump height derived from flight time was calculated for DJ, CMJ and SJ as follows:

$$Jump\ Height = 4.9 \times (0.5 \times Flight\ Time)^2$$

Due to the potential error in the flight time method (Moir, 2008), jump height derived from the cable displacement was also calculated for CMJ and SJ defined as the maximum displacement of the tether, displacing vertically into a cable-extension position transducer (PT5A, IDM instruments Pty Ltd, Australia) straight above the players' head. The difference between flight time and displacement methods for the CMJ and SJ was evaluated using Bland-Altman plots, which revealed that the flight time method underestimated jump height compared to the displacement method (see supplement, Figure S1). For jump specific analyses, the displacement method-derived values were used.

In addition to jump height, parameters calculated and stored in the database were, for CMJ and SJ, peak power, peak force and maximal rate of force development (maximal increase in force over a given 30ms time epoch) and for DJ, contact time. From the database, CMJ-SJ jump height difference and DJ reactive strength index (RSI), calculated as jump height divided by ground contact time, were determined. Finally, for CMJ and SJ peak force, power and RFD, the relative values were calculated by dividing the parameter values by players' body mass. Attempts producing the best jumping height for CMJ and SJ and RSI for DJ performance were selected for statistical analysis.

Statistical analyses

All data sets were checked for normality with the Shapiro-Wilk test. Two players' CMJ trials had to be excluded due to problems in the data. To account for the missing trials, a mixed effects model for repeated measures with fixed effects of jump type and age group and Tukey's tests for multiple comparisons was used to examine the effects of age group and jump type on jumping height derived from flight time (the jump height method available for all three jumps). For other SJ and CMJ analyses, jump height derived from displacement was used, due to potential error in the flight time method (Moir, 2008). All other jump parameters of interest were analysed either with one-way ANOVAs with Tukey's tests for multiple comparisons or Kruskal-Wallis tests with Dunn's multiple comparisons test in cases of significant Shapiro-Wilk tests. Significance was set at α = 0.05. Analyses were performed using Prism version 8 for Windows (GraphPad Software Inc., La Jolla, California, USA).

Results

Datasets from 60 players met our inclusion criteria and were extracted from the database for analysis (14 players did not have jump test data entered in the database as they were injured or were recovering from injury at the time of testing). The data sets included in this study were divided into three age groups: Age Group 1 (9–11y, n = 20, mean 10.6 ± 0.6y 144.8 ± 5.2cm 35.5 ± 4.82kg), Age Group 2 (12–14y, n = 24, mean 13.1 ± 0.8y 160.5 ± 7.2cm 49.6 ± 7.4kg) and Age Group 3 (15–19y, n = 16, mean 16.8 ± 1.3y 167.0 ± 7.7cm, 62.6 ± 7.2kg). Due to implausible values in the database, the CMJ test data for one participant of Age Group 1 and one participant of Age Group 2 were excluded from further analysis.

The mixed effects model for repeated measures with fixed effects of jump type and age group revealed significant effects of age group ($F_{(2,57)}$ = 15.17, P < 0.0001) and jump type ($F_{(1.975, 110.6)}$ = 66.04, P < 0.0001) on jump height (Figure 1), but no significant age group by jump type interaction ($F_{(4,112)}$ = 1.320, P = 0.2668). Tukey's multiple comparisons tests revealed that Age Group 3 jumped significantly higher than Age Groups 1 and 2, regardless of jump type, but that Age Groups 1 and 2 did not jump significantly different heights for any jump type (Figure 1 and Table 1). Within each age group, jump height was lowest during the DJ and greatest during the CMJ (Table 2). The one-way ANOVAs for CMJ and SJ height using the displacement method also revealed significant age group effects (Tables 3 and 4 and Supplementary Figures S2 and S3).

Analysis of body mass-normalised peak force, power and RFD for the CMJ and SJ revealed significant effects of age group on CMJ and SJ peak power only (Figure 2 and Table 3). For CMJ peak power, pairwise comparisons revealed significant differences between all age groups and for SJ peak power, between Age Group 3 and each of the younger groups (Figure 2 and Table 4). Analysis of the absolute peak force, peak power and peak RFD in the CMJ and SJ revealed significant effects of age group for all parameters (Supplementary Figures S2 and S3; Tables 3 and 4). Analysis of the CMJ-SJ difference did not reveal a significant effect of age on the difference (Supplementary Figure S4 and Table 3), with no significant pairwise comparisons between the groups (Table 4).

Analysis of the two DJ parameters contact time and RSI revealed significant effects of age group on the outcome (Figure 3 and Table 3), with pairwise comparisons revealing significantly shorter contact times and greater RSI for Age Group 3 compared to both younger groups (Table 4). As with DJ height, no significant difference was found between the two younger groups.

Discussion

The present retrospective study analysed performance data from CMJ, SJ and DJ testing of youth elite female soccer players within the same national training centre and training programme in the Netherlands. Significant age effects on jumping height were found for each of the three jumps, and pairwise comparisons revealed significant differences in jump height between the oldest age group and each of the younger age groups but not between the two younger age groups. Regarding the specific mechanisms of these jump height differences, we found for the CMJ and SJ, significant age effects on peak force, power and RFD, but only age effects on peak power remained significant after normalising the parameters to body mass. For the DJ, shorter ground contact times and, therefore, greater RSI in the oldest group was associated with their superior jump height.
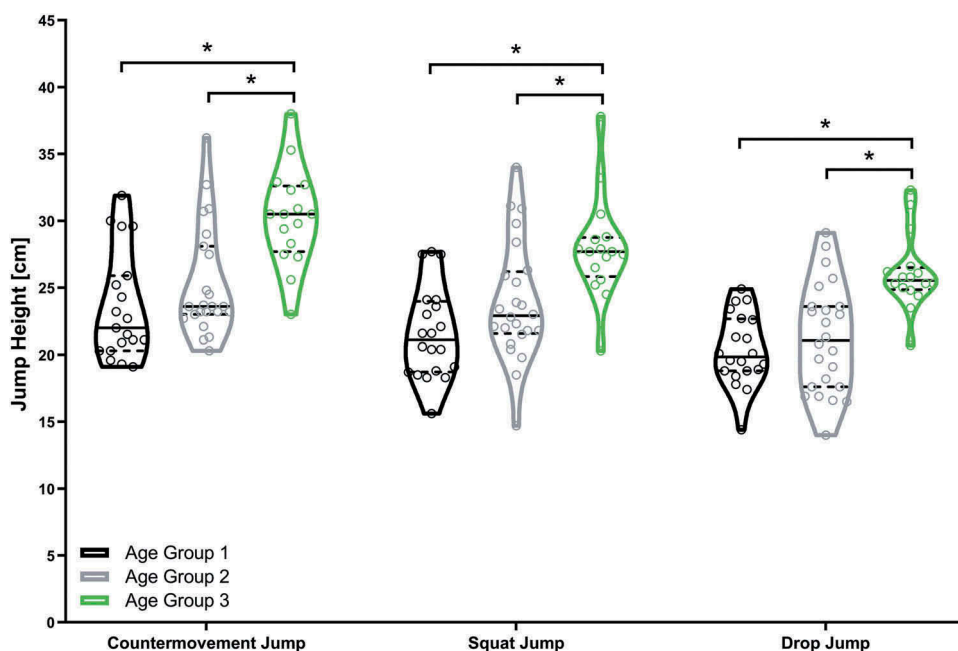
Figure 1. Jump height derived from flight time for the three age groups during countermovement, squat and drop jumps displayed as violin plots and individual data points with solid lines indicating the medians and dashed lines indicating the quartiles. *: Statistically significant difference (P < 0.05).

Table 1. Effect sizes and significance values for the post hoc pairwise comparison tests between age groups for jump height.

		Age Group 1 vs. 2	Age Group 1 vs. 3	Age Group 2 vs. 3
CMJ Height	Cohen's d	0.429	1.747	1.281
(flight time)	P	0.3559	**<0.0001**	**0.001**
SJ Height (flight	Cohen's d	0.596	1.760	0.971
time)	P	0.1255	**<0.0001**	**0.0116**
*DJ Height	Cohen's d	0.251	2.097	1.398
(flight time)	P	0.6747	**<0.0001**	**0.0002**

Bold text highlights the statistically significant outcomes.
*These parameters were analysed with the Kruskal-Wallis test and Dunn's multiple comparisons test. All others were analysed with Tukey's multiple comparisons test.

Table 2. Effect sizes and significance values for the post hoc pairwise comparison tests between jump types for jump height.

		CMJ vs. SJ	CMJ vs. DJ	DJ vs. SJ
Age Group 1	Cohen's d	0.397	0.933	0.530
	P	**0.0104**	**0.0004**	**0.0307**
Age Group 2	Cohen's d	0.637	1.000	0.324
	P	**0.0052**	**<0.0001**	**0.0021**
Age Group 3	Cohen's d	0.798	1.000	0.569
	P	**0.0004**	**<0.0001**	**0.0009**

Bold text highlights the statistically significant outcomes.

Table 3. One-way ANOVA results for the assessed jump parameters.

	df	F	P	η^2
CMJ Height (displacement)	2, 55	7.512	**0.0013**	0.214507
*CMJ Peak Force		*26.98	**<0.0001**	
CMJ Peak Force (relative)	2, 55	0.3347	0.717	0.012025
CMJ Peak Power	2, 55	76.36	**<0.0001**	0.735212
CMJ Peak Power (relative)	2, 55	14.94	**<0.0001**	0.352086
CMJ Peak RFD	2, 55	18.59	**<0.0001**	0.403395
CMJ Peak RFD (relative)	2, 55	0.8828	0.4194	0.031103
SJ Height (displacement)	2, 57	8.089	**0.0008**	0.22102
SJ Peak Force	2, 57	21.34	**<0.0001**	0.428157
SJ Peak Force (relative)	2, 57	1.259	0.2918	0.042303
SJ Peak Power	2, 57	78.60	**<0.0001**	0.733887
SJ Peak Power (relative)	2, 57	14.53	**<0.0001**	0.337662
SJ Peak RFD	2, 57	13.54	**<0.0001**	0.322032
SJ Peak RFD (relative)	2, 57	0.3644	0.6962	0.012625
CMJ-SJ Difference	2, 55	0.1754	0.8396	0.006338
DJ Contact Time	2, 57	4.968	**0.0103**	0.148352
*DJ RSI		*21.4	**<0.0001**	

Bold text highlights the statistically significant outcomes.
*These parameters were analysed with the Kruskal-Wallis test and the Kruskal-Wallis statistic is reported in the F column.

regarding the age-jumping performance relationship (Castagna & Castellini, 2013; Mujika et al., 2009; Vescovi et al., 2011). Previous findings suggest that jumping performance improves until the age range of 16–19 (Vescovi et al., 2011), but does not further improve when turning from junior to senior in female soccer (Castagna & Castellini, 2013). However, Mujika et al. (2009) reported a better jumping performance for their senior female soccer players (23.1 ± 2.9 years, n = 17) compared to their junior players (17.3 ± 1.6 years, n = 17). Differences in results between studies might be due to sample sizes, participants originating from different teams, training programmes, or competitions and varying training status due to timing of testing during the season. The present study does not suffer from many of these limitations as all participants were from the same training programme, were competing at equivalent competition levels and were tested at the same time

To the best of our knowledge, this is the first study that elucidates jumping performance by examining the biomechanical mechanisms of three different jumps with different task demands in youth elite female soccer players from the same national development programme. The results of the present study clearly showed that elite female soccer players in the age range of 15–19 jumped higher during CMJ, SJ and DJ than equivalent (in the sense of competition level and training environment) players of younger age categories. No significant differences in jumping height were found between the two younger age groups. There is inconsistency in the literature

Table 4. Effect sizes and significance values for the post hoc pairwise comparison tests for the jump parameters.

		Age Group 1 vs. 2	Age Group 1 vs. 3	Age Group 2 vs. 3
CMJ Height (displacement)	Cohen's d	0.50204	1.501695	0.791616
	P	0.2062	**0.0008**	0.052
*CMJ Peak Force	Cohen's d	1.072345	2.213197	1.230564
	P	**0.0207**	**<0.0001**	**0.0135**
CMJ Peak Force (relative)	Cohen's d	0.000542	0.246895	0.259758
	P	>0.9999	0.7605	0.7411
CMJ Peak Power	Cohen's d	2.163619	4.271573	1.992558
	P	**<0.0001**	**<0.0001**	**<0.0001**
CMJ Peak Power (relative)	Cohen's d	0.842971	1.930847	0.9743
	P	**0.0304**	**<0.0001**	**0.0063**
CMJ Peak RFD	Cohen's d	0.861675	2.078965	1.167775
	P	**0.0283**	**<0.0001**	**0.001**
CMJ Peak RFD (relative)	Cohen's d	0.077714	0.465144	0.356387
	P	0.9611	0.4231	0.5435
SJ Height (displacement)	Cohen's d	0.394843	1.514512	0.931129
	P	0.3551	**0.0006**	**0.0176**
SJ Peak Force	Cohen's d	0.703957	2.26684	1.469699
	P	0.0517	**<0.0001**	**0.0001**
SJ Peak Force (relative)	Cohen's d	0.429381	0.184479	0.348512
	P	0.2693	0.8524	0.638
SJ Peak Power	Cohen's d	1.849392	4.686779	2.206918
	P	**<0.0001**	**<0.0001**	**<0.0001**
SJ Peak Power (relative)	Cohen's d	0.639943	1.845945	1.113926
	P	0.1076	**<0.0001**	**0.0017**
SJ Peak RFD	Cohen's d	0.620453	1.759564	1.121341
	P	0.1032	**<0.0001**	**0.0032**
SJ Peak RFD (relative)	Cohen's d	0.142896	0.117565	0.311752
	P	0.8658	0.9375	0.6822
CMJ-SJ Difference	Cohen's d	0.04713	0.218995	0.141746
	P	0.9866	0.8351	0.8954
DJ Contact Time	Cohen's d	0.184616	1.250036	0.822418
	P	0.7931	**0.0109**	**0.0388**
*DJ RSI	Cohen's d	0.361522	2.296496	1.358129
	P	>0.9999	**<0.0001**	**0.0003**

Bold text highlights the statistically significant outcomes.
*These parameters were analysed with the Kruskal-Wallis test and Dunn's multiple comparisons test. All others were analysed with Tukey's multiple comparisons test.

point in the competitive season. Our findings tend to agree with those of Mujika et al. (2009), as we show that jumping performance was greatest after the age of 15, although it should be noted that their post-adolescent groups also differed in competitive level. Although the differences found in jumping height were largest between the oldest players and the youngest players, significant differences were also found between Age Groups 2 and 3. Twenty-eight and 25 players in the present study showed superior jumping performance, according to the standards of 34.4cm and 32.9cm for the CMJ and SJ, respectively set by Castagna and Castellini (2013). While this indicates that the players in the current study were of a high level in terms of jumping performance, differences in training and competition status of the players and in the equipment used across studies make direct comparisons of the absolute jump heights between studies difficult.

Regarding DJ performance, no differences were found between the two youngest age groups. Only Age Group 3 jumped significantly higher with significantly shorter contact times compared to the two youngest age groups. These performance differences are similar to the CMJ performance differences in the present study, which is not surprising since DJ performance improvement is shown to be associated with CMJ performance improvement (Sheppard, Chapman, Gough, McGuigan, & Newton, 2009). These results indicate that the ability to tolerate stretch-load during movements like the DJ is not yet maximised in the younger age categories but develops particularly after the age of 15 years.

As could be expected, we found that age influenced peak force, power and RFD in both CMJ and SJ. Across the age groups, the players became heavier, and part of this increase will no doubt have been due to increases in muscle mass due to physical maturity and physical training. However, when normalised for body mass, only peak power during CMJ and SJ were significantly affected by age group. This suggests that while the older players could produce higher absolute peak forces and RFD during the CMJ and SJ, this probably does not explain the age-related differences in jump height, because all groups produced similar relative peak forces and RFD. Therefore, it appears that the jump height differences found in CMJ and SJ across the age groups may have been predominantly driven by the significant difference in relative peak power during the jumps. The effect sizes in Table 4 also support this conclusion, as these are much greater for CMJ and SJ peak power (absolute and relative) than the other parameters. Furthermore, of the normalised parameters, relative CMJ peak power was the only parameter that was significantly different between the two younger age groups.

Since power is the product of force and velocity, it is interesting to look at the peak force across the age groups to further understand the age-related changes in peak power for jumping performance. As shown in Table 4, the effect sizes of peak force for SJ and CMJ are smaller between Age Groups 1 and 2 than between Age Groups 2 and 3. Since peak force seems not to be a decisive factor for jump height between the two youngest
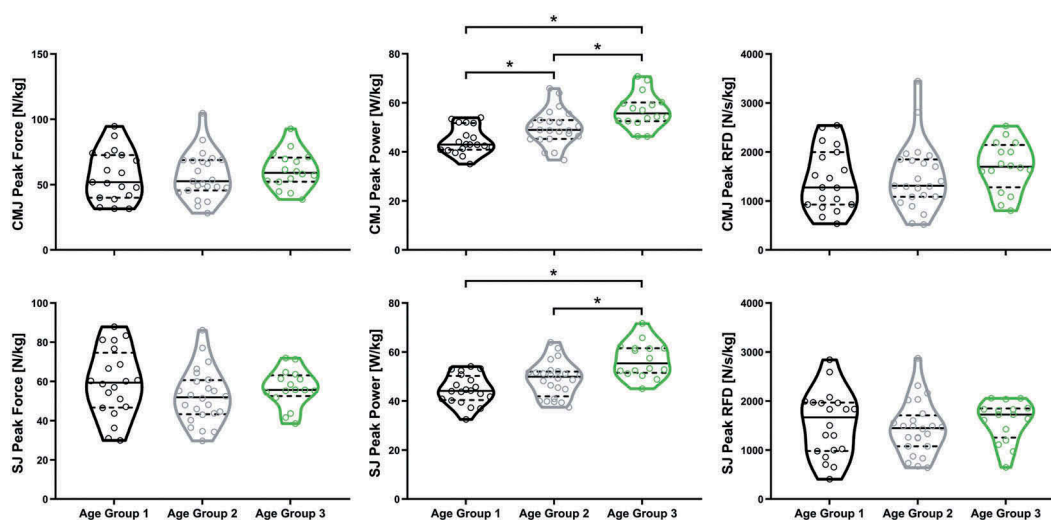
Figure 2. Peak force, power and rate of force development (RFD) relative to body mass during the countermovement jump (CMJ) and squat jump (SJ) across the three age groups displayed as violin plots and individual data points with solid lines indicating the medians and dashed lines indicating the quartiles. *: Statistically significant difference (P < 0.05).

Figure 3. Contact time and reactive strength index (RSI) for the drop jump (DJ) across the three age groups displayed as violin plots and individual data points with solid lines indicating the medians and dashed lines indicating the quartiles. *: Statistically significant difference (P < 0.05).
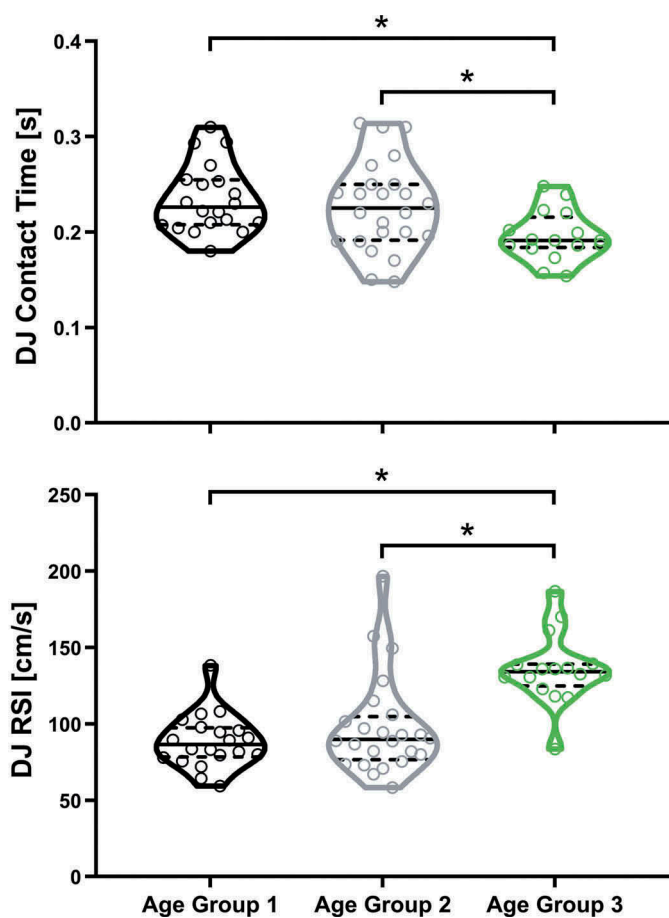
age groups, these results provide evidence for peak power being reached mainly due to a high velocity of force application in the younger players, while peak force becomes more important for peak power in the older players. Based on these results,

coaches interested in improving CMJ and SJ performance may choose to target velocity of force application or absolute force production differentially based on the age of their athletes.

Contrary to what was expected based on previous findings (Castagna & Castellini, 2013), there were no significant differences across the age groups in SSC efficiency, which represents the utilisation of elastic energy via an eccentric and concentric muscle action combination (Sheppard et al., 2008; Van Hooren & Zolotarjova, 2017; Wang & Zhang, 2016). However, CMJ-SJ difference might also indicate better utilisation of pretension to reduce muscle slack in the SJ, instead of a better utilisation of the SSC in the CMJ (Van Hooren & Zolotarjova, 2017). The lack of difference between the older players and younger players in the present study might thus be due to a better execution of the SJ, instead of a less developed ability to use the SSC in the CMJ. Future research should consider experience and expertise in performing jumping tests as a factor that may contribute to performance, in addition to physiological and biomechanical characteristics. This knowledge could lead to more informed coaching practice related to training and testing of jump performance in athletes of different ages.

Given the nature of the data collection as part of the regular testing protocol of a training centre, some limitations in the current study should be kept in mind. Although movement quality was verified by the strength and conditioning coach, the knee angle in SJ performance for example, was not monitored with a computerised goniometer (Castagna & Castellini, 2013) or motion capture system. Furthermore, the equipment used for the testing may not compare in accuracy to a typical research laboratory force plate. However, as the protocol was strictly standardised and was the same for all players, we do not think that these drawbacks have greatly influenced the findings of the study. Additionally, it is important to highlight that this was not a longitudinal study, and results and conclusions related to age-related effects should be interpreted with this in mind. Finally, as mentioned in the methods section, data on pubertal status was not available, and such information might have provided more detailed insight into the developmental

stages of the athletes in relation to performance. Future studies should aim to assess the development of jumping performance over time to confirm if the cross-sectional age-effects in this study are also relevant longitudinally. Additionally, intervention studies specifically training individual biomechanical mechanisms of jumping performance would help elucidate the causal role of said parameters in jumping performance.

In conclusion, the current findings show that among youth elite female soccer players, age significantly affects jumping performance. These age-related differences appear to be primarily driven by the capacity for power production during CMJ and SJ tasks, and by the ability to jump with shorter ground contact times during DJ.

Acknowledgments

Disclosure statement

No potential conflict of interest was reported by the authors.

Data availability statement

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

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