The influence of age and maturity status on the maximum and explosive strength characteristics of elite youth female soccer players

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Abstract

Research has characterised the strength characteristics of elite youth male soccer players, although little is known about female players. This study investigated the influence of age and maturity status on strength characteristics in 157 female soccer players (U16*;* *n*=46, U14*;* *n*=43, U12*;* *n*=38, U10*;* *n*=30), recruited from three elite female soccer academies. Linear mixed models were used to determine the difference by age or maturation. **Peak force (PF)** was *possibly* and *likely* greater for older age groups, however relative **PF** was *most likely trivial* between consecutive age groups. Relative impulse at 100 and 300 ms was *very likely* greater at U12 than U10, *likely* and *possibly* less at U12 than U14, and *most likely* less and *possibly* greater at U16 than U14. Relative **PF** was *likely* less at Pre **peak height velocity (PHV)** than Circa and Circa than Post-PHV. Relative Impulse at 100 and 300 ms was *most likely* lower for Pre-PHV than Circa and Pre-PHV than Post-PHV, and *possible* greater at Circa than Post-PHV. Age and maturation impact upon PF and impulse, thus practitioners should account for individual maturation status when comparing players. These data provide **reference** strength data for elite youth female soccer players, which can be used when monitoring player development.

Key words: soccer, youth, maturation, strength

Introduction

The popularity and professionalism of female soccer has increased markedly in recent years, with elite senior players now employed on either a professional or semi-professional basis. The increased professionalism has resulted in the growth of elite female soccer academies for youth players (9-16 years), designed to develop the next generation of elite senior International players (Wright and Lass, 2016). As part of the training programme, youth elite female soccer players now regularly undertake strength and conditioning training and scheduled fitness testing throughout the season to monitor their development.

During a match, senior level female soccer players have been reported to cover approximately 10 km, with 1.7 km completed at high-speed running (>18 $km \cdot h^{-1}$; Datson et al., 2014). A match also consists of explosive actions such as sprints, jumps, tackling and change of direction (COD), that appear to determine the outcome of games (Mohr et al., 2008). Given the relationships between strength and athletic performance (Suchomel, Nimphius and Stone. 2016), it is important that strength training is included within a player's development programme (Le Gall et al., 2010).

While research has characterised the strength characteristics of elite youth male soccer players (Deprez et al., 2015; Comfort et al., 2014; Philippaerts, et al., 2006; Gissis et al., 2006), little is known about the strength characteristics of youth female players. Findings from studies including youth male athletes may not be transferable to female athletes, especially during maturation, given the differences in the timing and tempo and their differences in physical and physiological characteristics from the onset of puberty (Lloyd and Oliver, 2012). Vescovi et al. (2010) investigated lower body power characteristics via a countermovement jump (CMJ), observing improvements with age (Under 12s (U12) and U13 had lower CMJ heights than U17–U21) in United States female soccer players. While findings from this study provide comparative data for youth female soccer players, the authors did not consider the influence of maturation on performance, which has been shown to significantly influence the performance of youth male soccer players (Lovell et al., 2015). As such less is known about the maximum and explosive strength qualities of young females soccer players during different stages of maturation (Wright and Laas, 2016). The Football Association (FA) have recently highlighted the need for female soccer players to improve their "athleticism' (Campbell, 2017), thus the quantification of strength characteristics within youth female soccer players can provide practitioners with data to compare players against, informing specific interventions.

The assessment of strength in young athletes can be somewhat problematic in comparison to senior athletes. Young athletes may not have an appropriate training age, as such traditional strength testing methods (i.e. one repetition maximum) may not be safe. The isometric mid-thigh pull (IMTP) is an alternate strength assessment method, which has been reported to be both a safe and reliable (ICC = 0.95, CV = 4%) strength assessment with low measurement error (Haff et al., 2015; Dos Santos et al., 2016), and has a strong correlation with dynamic performance (Stone et al., 2004; McGuigan et al., 2010).

Therefore, the purpose of this study was to quantify the strength characteristics of elite youth female soccer players (i.e., U10, U12, U14 and U16) using the IMTP, while considering maturation status of players. Such information is important to aid the design of strength and conditioning programmes for this cohort to enhance the "athleticism" of players, as highlighted by the FA. Furthermore, such data can be used as reference data when assessing the effectiveness of training interventions and monitoring player development.

Methods

The purpose of this study was to determine the IMTP characteristics of elite youth female soccer players from U10 - U16 and investigate the influence of age and maturation on strength characteristics. Anthropometric (standing height, sitting height, body mass and leg length) and IMTP characteristics were collected following preseason in September, which was the start of the 2016-2017 season. Players from three elite female soccer academies were familiarised with the IMTP prior to the commencement of the study.

Subjects

157 female soccer players (U16*;* *n* = 46, U14*;* *n* = 43, U12*;* *n* = 38, U10*;* *n* = 30) were recruited from three elite Tier 1 female soccer academies in England. Subjects were considered elite, as they were part of a Tier 1 Regional Talent Centre, which is the highest standard of female youth club soccer in England. All three academies trained for approximately 36 weeks per year. U16 and U14 players completed approximately six hours of field based soccer training and

approximately two hours of strength and conditioning sessions per week. U12 and U10 players completed approximately four hours of field based soccer training and approximately one hour of strength and conditioning per week. Prior to participating in the study, institutional ethics approval was gained and players and their parents/guardians provided assent/consent. Age categories were defined by chronological age on the 1st September 2016, which established their status for competition and training squads.

Procedures

All testing was carried out at the start of the 2016 season. Testing was conducted a minimum of 48 hours post competitive match play or training at each respective academy. On arrival subjects completed anthropometric assessments prior to undertaking a standardised warm up before completing the IMTP test. The standardised warm up consisted of dynamic stretching, followed by 3 IMTP efforts at individual perceived increasing intensities (50, 70 and 90% maximum efforts) with 1-minute rest between repetitions.

Anthropometry

Subjects standing height (cm) and sitting height (cm) were recorded to the nearest 0.1cm using a 132 Seca Alpha stadiometer following the standard protocol outlined by Ross et al., (1991). Body mass was measured on a commercially available portable force platform (AMTI, ACP, Watertown, MA) using a sampling rate of 1000 Hz then multiplied by 9.81 to convert to kg. Body mass was taken to be BWg^{-1} (kg) with g = acceleration due to gravity.

Age and Maturity Offset

Chronological age was calculated as the difference between date of birth and the date of assessment. To estimate maturity status, age at peak height velocity (PHV) was calculated using the Mirwald et al. (2002) equation. The Mirwald equation has been reported to be a reliable (R^2= 0.91, SEE=0.50), non-invasive practical solution for the measure of biological maturity (Mirwald et al., 2002). Years from PHV was calculated for each subjects by subtracting the age at PHV from chronological age. Subjects were also classified into 3 pre-defined groups; Pre-PHV (offset < -1 years), Circa-PHV (≤ ±1 years) or Post-PHV (offset > +1 years) in relation to their years from PHV (YPHV), which is consistent with previous literature (Cunha et al., 2015; Hammami et al., 2016).

Isometric Mid-Thigh Pull

The IMTP was performed on a commercially available portable force platform (AMTI, ACP, Watertown, MA) with a sampling rate of 1000 Hz, which is consistent with previous methodologies (Dos'Santos et al., 2016; Haff et al., 2015). Subjects performed the IMTP on a customized pull rack, in a self-selected position similar to that of the second pull of a power clean, with a flat trunk position and their shoulders in line with the bar (Haff et al., 2015). Research has previously demonstrated that differences in knee and hip joint angles during the IMTP do not influence kinetic variables (Comfort et al., 2015), justifying the self-selected preferred mid-thigh position.

Prior to commencement of the testing, subjects were given two practice trials. Consistent with previous methodologies (Dos'Santos et al., 2016), subjects were instructed to pull as “fast and hard” as possible, and received loud, verbal encouragement. Each subject completed two trials lasting 5 seconds, with 3-5 minutes of rest between each trial, which is consistent with previous literature (Dos’Santos et al., 2016).

The highest peak force (PF) achieved over the 2 trials was considered the subjects best trial. PF was identified as the maximum force value obtained during the best trial of the IMTP. In addition to highest PF, relative (to body mass) PF and impulse were also measured at time specific force values (100 and 300 ms). The vertical force–time curve was integrated over 100 and 300 ms windows from the onset of contraction (when the vertical force increased above a threshold of 40 N) to calculate measures of impulse. Net impulse allows quantification of the mechanism that underpin movement (Mundy et al., 2016) Impulse at 100 and 300 ms was chosen as this was consistent with previous values used in the literature and used because these are consistent with similar ground reaction times for sprinting, various jumps and change of direction (Weyand, Lin, Bundle, 2006). Relative values were calculated using the ratio scaling method (i.e. Impulse / body mass; Jacobsen, 2013). The reliability data from the two maximal trials for the measured variables can be seen for each respective age group in Table 1.

******Table 1 near here ******

Statistical Analyses

A linear mixed model was used to determine the difference between age or maturation group (each defined as a fixed factor), while accounting for potential differences between academies (defined as a random factor). Magnitude based-inferences were used to assess for practical significance (Hopkins et al., 2009). The threshold for a difference to be considered practically important (the smallest worthwhile difference; SWD) was set at 0.2 x between subject standard deviation (SD), based on Cohen's *d* effect size (ES) principle. The probability that the magnitude of difference was greater than the SWD was rated as <0.5%, *almost certainly not*; 0.5-5%, *very unlikely*; 5-25%, *unlikely*; 25-75%, *possibly*; 75-95%, *likely*; 95-99.5%, *very likely*; >99.5%, *almost certainly* (Hopkins et al., 2009). Where the 90% Confidence Interval (CI) crossed both the upper and lower boundaries of the SWD (ES±0.2), the magnitude of difference was described as *unclear* (Hopkins et al., 2009). ES were rated as *trivial* (<0.2), *small* (0.2-0.59), *moderate* (0.6-0.19) *large* (1.2-1.99) or *very large* (2.0-4.0) (Hopkins et al., 2009).

Results

Table 1 presents the anthropometric and IMTP characteristics by annual age category. Height and body mass was *most likely* to *possibly* greater in older age groups. PF was *possibly* and *likely* greater for older age groups, however differences in relative PF were *most likely trivial* between consecutive age groups. Impulse (100 and 300 ms) was *very likely* and *most likely* greater for U12 than U10, and *likely* greater for U16 than U14. The difference in impulse between U12 and U14 was *possibly trivial* at 100 ms and *most likely greater* at U14 at 300 ms. Relative impulse at 100 and 300 ms was *very likely* greater at

U12 than U10, *likely* and *possibly* less at U12 than U14, most *likely* and *possibly* greater at U16 than U14.

****Table 2 near here****

Table 2 presents the anthropometric and IMTP characteristics for each maturity off-set group. Height and body mass were *very likely* to *possibly* greater for more mature players. Peak force was *most likely* to *very likely* greater for more mature players. However, relative PF was *likely* less at Circa-PHV and Post-PHV than Pre-PHV. Impulse at 100 ms was *likely* greater at Pre-PHV than Circa-PHV and *likely greater* at Post-PHV than Pre-PHV. Impulse at 300 ms was *possibly* and *likely* greater for more mature players. Relative impulse at 100 and 300 ms was *most likely* lower at Circa-PHV than Pre-PHV and most likely lower Post-PHV than Pre-PHV.

****Table 3 near here****

Discussion

The purpose of this study was to investigate the influence of age and maturation on strength characteristics, and provide reference force-time data for youth female soccer players. Findings suggest maturation influences absolute PF in youth female soccer players but has less effect on relative PF and impulse. Therefore, when absolute measures of IMTP strength are evaluated and used to compare between athletes of the same age, practitioners should account for maturation status of individual athletes when evaluating strength qualities. These data provide reference strength data for elite youth female soccer players, which can be used when monitoring player development.

Influence of Age on Peak Force and Impulse

To the authors knowledge this is the first study to provide strength data for youth female athletes by annual age groups using the IMTP. Findings suggest that absolute PF is greater in older player, which is consistent with previous literature demonstrating an increase in absolute strength of knee strength extensors (143%) and flexors (131%) until the age of 14 years when strength was observed to plateau (De Ste Croix et al., 1999). However, when PF was made relative to body mass differences were *most likely trivial* between consecutive age groups, highlighting the influence of body mass on absolute peak force. These findings demonstrate that when body mass is considered, performance in maximal strength qualities are similar between consecutive age groups and should be considered when making comparisons between youth athletes of different sizes.

While PF is a good indicator of maximum strength, it does not provide information about the explosive qualities of the athlete. As such, net impulse provides data on the force-time characteristics, useful for practitioners looking to prescribe individual strength programmes (i.e. force vs. velocity development). This study demonstrates that both absolute and relative impulse at 100 and 300 ms increased from U10 to U12. Although it is not possible to determine from this study the specific mechanism for this improvement, this is potentially due to the development of neurological factors associated with children of this chronological age, where development of the neuromuscular system naturally accelerates due to increased myelination and motor unit synchronization (Malina, 2004), which are associated with improvements in explosive force production in children (Lloyd et al., 2011). In contrast, differences in impulse at 100 ms were possibly trivial between U12-U14s and likely decreased between age categories when made relative to body mass. Between U14 and U16, female soccer players experience greater absolute and relative impulse at 100 and 300 ms. Training age and specifically strength training age, in addition to chronological age could explain the differences in performance, which unfortunately were not quantified in this study.

The development of muscular strength is multi-faceted and underpinned by hormonal, muscular, neural, and mechanical factors (De Ste Croix, 2015) and confounded by factors such as body mass and stature (Ford et al., 2011). Between the ages of 11-14 years represented by these annual age categories (U12-U14s) females are experiencing a period of accelerated physical development evidenced by the large increase in body mass and stature in the present study. Females have also been reported to experience an increase in fat mass around peak weight velocity (Ford et al., 2011), which may explain why relative measures decreased, due to the non-functional role of fat for athletic performance. It is not possible to determine the specific mechanisms for the observed difference between age groups in this study. Therefore, further research should investigate the influence of lean body mass development on the strength characteristics of youth female soccer players, which was not collected in this study.

Beyond the age of 16 years players do not remain in a FA soccer academies in England, which are defined as development environments. As such, strength changes into adulthood within this population is unclear and warrants further investigation, given that previous research has demonstrated that female athletes continue to demonstrate improvements in physical performance until 21 years (Vescovi et al., 2011).

Influence of Maturation on Peak Force and Impulse

Findings of this study show that maturation impacts upon the development of both PF and impulse in elite youth female soccer players. PF and impulse were greater in more mature players, which is consistent with observations in youth male soccer players, where maturation status has been observed to be a strong indicator of physical performance (Lloyd et al., 2015; Buchheit and Mendez-Vilanueva, 2013; Vandendriessche et al., 2012). These changes can be attributed to the normal development of strength resultant from growth and maturation. During this time there are marked changes in the central nervous system and morphological changes of the muscle including muscular, neural and mechanical factors resulting in an increase in muscular strength (Malina, 2004; Ford et al., 2011).

When PF and impulse were made relative to body mass, findings show that PF and impulse at 100 and 300 ms were lower at Circa-PHV in comparison to Pre-PHV. Furthermore, even when body mass is accounted for, relative impulse 100 and 300 ms and relative PF were lower Post-PHV in comparison to Pre-PHV, suggesting that a strength deficit develops in youth female soccer players. These finding are consistent with previous literature which has reported that female adolescents experience a significant regression in hip abduction strength relative to body mass in the year they transition from pre-pubertal to pubertal status and a decrease in relative strength from pre-post maturation (Quatman-Yates et al., 2013). These observations are important for practitioners, who should acknowledge there is potentially a decrease in performance, despite the increase in maturation status.

Given that the findings of this study show that relative strength was greatest Pre-PHV, the most beneficial time to initiate neuromuscular integrative training programs may be during pre-adolescence, prior to the period of pubertal maturation when youths are growing most rapidly (Myer et al., 2011), which may also attenuate the decrease in strength during PHV. It is recommended that youth female soccer players regularly undertake a structured and progressive strength and conditioning programme that aims to develop the neuromuscular system Pre-PHV and Circa-PHV and targets both neural and morphological changes Post-PHV for both a performance improvement and as an injury prevention strategy. Noteworthy, it is only in recent years that the prevalence of supplementary strength training in youth female soccer academies has increased, in addition research has reported that compliance of female soccer players to neuromuscular training programs can be low (Rubley et al., 2011; Wright and Lass, 2016). Therefore, there is a need for continued education for both players, coaching staff and parents within female soccer academies to develop a culture and compliance to strength development, given the relationship with improved physical performance and reduce injury risk factors when implemented successfully.

Future studies should evaluate strength development longitudinally, as a limitation of this study was the cross-sectional design. Furthermore, monitoring of other anthropometric and physical qualities may be advantageous to develop a greater understanding of the development trajectories of youth female soccer players. A further limitation of this study is that strength variables were expressed relative to body mass, whereas future studies should explore strength relative to lean mass or allometrically scaled. This study also found varying levels of within reliability for measures by age group. For example, impulse at 100 ms for U10 players may be erroneous given the within session reliability (ICC = 0.711, CV = 13.8%), which may be attributed to their limited training age, and should be a consideration when interpreting findings from young players. A further limitation of this study was not having information on the specific training age, or strength training age of the players, or information on the menstrual cycle of players, which may have impacted the observed findings. Finally, it is not possible to determine from this study the specific mechanism for the differences observed, therefore future research should look to consider the above limitations when evaluating the strength characteristics and longitudinal development in female soccer players.

In conclusion, the present study presents reference IMTP force-time characteristics of elite youth female soccer players aged between 9-16 years by both annual age group and maturation status. Findings suggest that a strength deficit may develop in youth female soccer players. It is recommended that youth female soccer player regularly undertake a structured and progressive strength and conditioning programme that aims to develop the neuromuscular system Pre-PHV and Circa-PHV and targets both neural and morphological changes Post-PHV.

Practical Applications

Findings of this study provide reference data for English youth female soccer players by annual age category and maturation groups. It is recommended that such data should be used by strength and conditioning coaches and other practitioners working with youth players when assessing individual player's strengths and weaknesses, as well as monitoring longitudinal player development. Given that relative strength was lower in Post-PHV players, it is important that youth female soccer players are regularly undertaking structured strength training as part of their weekly training structure to maximise longitudinal physical development, given the know relationship between strength and explosive activities (e.g., sprint ability, Sanders et al., 2013), and injury risk (Suchomel, Nimphius, and Stone, 2016).

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