Hall, ECR, Larruskain, J, Gil, SM, Lekue, JA, Baumert, P, Rienzi, E, Moreno, S, Tannure, M, Murtagh, CF, Ade, JD, Squires, P, Orme, P, Anderson, L, Whitworth-Turner, CM, Morton, JP, Drust, B, Williams, AG and Erskine, RM

Injury risk is greater in physically mature versus biologically younger male soccer players from academies in different countries

Injury risk is greater in physically mature *versus* biologically younger male soccer players from academies in different countries

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Acknowledgements

We are extremely grateful to the following individuals for their assistance with data collection: Sam Temple, Dr Mateo Gamarra, Dr Emiliano Vigna, Dr Gustavo Schmitner, Dr Luisina Passarello, Daniel Silva, Diego Morena, Bruno Jotta Costa and John Chaffe.

Abstract

Objectives: To investigate if maturity status was associated with injury risk in male academy soccer players.

Design: Prospective cohort surveillance study.

Setting: Professional soccer academies.

Participants: 501 players (aged 9-23 years) from eight academies in England, Spain, Uruguay and Brazil.

Main outcome measures: Players were grouped by maturity offset as pre-peak height velocity (PHV), circa-PHV, post-PHV or adult. Injury prevalence proportion (IPP) and days missed were recorded for one season per player, with training/match exposure recorded in a sub-sample (n=166).

Results: IPP for all injuries combined increased with advancing maturity, with circa-PHV (p=0.032), post-PHV (p<0.001) and adult (p<0.001) higher than pre-PHV. IPP was higher in post-PHV and adult than pre-PHV for non-contact (p=0.001 and p=0.012), soft-tissue (both p<0.001), non-contact soft-tissue (p<0.001 and p=0.005), muscle (both p<0.001), thigh (both p<0.001), ankle (p=0.035 and p=0.007) and hamstring injuries (p=0.041 and p=0.017). Ligament/tendon IPP was greater in adult versus pre-PHV (p=0.002). IPP for growth-related injuries was lower in post-PHV than pre-PHV (p=0.039). Injury incidence rates (n=166) exhibited similar patterns to IPP in the full cohort.

Conclusions: Injury patterns were similar between post-PHV and adult academy players but, crucially, relatively more of these groups suffered injuries compared to pre- and circa-PHV (except growth-related injuries).

Key words: adolescence; peak height velocity; maturity; maturation; football

Introduction

Injuries in academy soccer players contribute to the potential loss of 6-11% of development time (Le Gall et al., 2007; Price et al., 2004) and are negatively associated with player progression (Larruskain et al., 2021). Injury frequency in academy soccer players has been shown to increase with chronological age (Price et al., 2004), potentially related to increases in both the volume and intensity of soccer activity as players progress through the academy system (Price et al., 2004; Read et al., 2017. Due to the spectrum of age groups within a soccer academy (under 9 (U9) to U21), academy soccer players who train and compete throughout their teenage years will experience considerable changes in physical stature through the process of biological maturation (Figueiredo et al., 2010). There is some evidence that more severe injuries are recorded around 14 years old (Hall et al., 2020; Le Gall et al., 2007) coinciding with the age at which most males undergo their fastest rate of somatic growth, termed peak height velocity (PHV) (Mirwald et al., 2002). This period is characterised by sharp increases in height and occurs in advance of peak weight velocity (Philippaerts et al., 2006). When combined, it is possible that drastic changes in the length, weight and size of the trunk and limbs could acutely impair coordination, movement mechanics and motor task performance, heightening injury risk. With academy soccer players competing according to chronological age, those maturing later may be comparatively smaller, lighter, and weaker than their peers. In conjunction with increasing volumes and intensities of soccer activity as academy soccer players advance through chronological age groups, such discrepancies may lead to varied internal loads. Accordingly, this has the potential to make academy soccer players are more susceptible to injury at specific stages of maturation, rather than their chronological age.

Some evidence suggests that injuries in academy soccer players peak around PHV (Johnson et al., 2020; Van der Sluis et al., 2015), and that the timing (chronological age) at which individual players undergo PHV is also associated with injury (Monasterio et al., 2021; Van der Sluis et al., 2014; Wik et al., 2020). However, other studies suggest that a higher frequency of injuries occurs in post-PHV players (Monasterio et al., 2020) and that injury burden increases with advancing maturity status (Monasterio et al., 2021), while another report suggests there is no relationship between maturity status and injury pattern (Light et al., 2021). Although these studies benefit from longitudinal data over consecutive seasons, each report on the link between injury and maturity status is derived from a single academy and/or country (Bult et al., 2018; Johnson et al., 2020; Light et al., 2020; Monasterio et al., 2020, Monasterio et al., 2021, Van der Sluis et al., 2014, Van der Sluis et al., 2015), which limits the generalisation to other clubs and/or countries. The potential for differences in training regimes, playing styles, data recording and governance structures within and/or between clubs, and within and/or between different countries, might influence the conclusions of existing literature, underpinning the need for larger and more ecological valid samples derived from multiple clubs and countries. Moreover, the number of individual players that can be studied in a single academy is limited, and to our knowledge, the largest sample in a study investigating biological maturity as an injury risk factor in youth soccer is a single club study of 283 individual players (Materne et al., 2020). Though multi-club studies of injury in academy soccer players are available (Hall et al., 2020; Materne et al., 2020; Price et al., 2004; Read et al., 2017), these are descriptive in nature and do not investigate specific risk factors. Therefore, studies investigating the influence of maturity status in multiple academies from different countries are required to improve current improve the external validity of the current evidence base. Only one study has considered the broad age range of players in a soccer academy who can be grouped as post-PHV by including an "adult" category (Monasterio et al., 2021). However, this was reported in a limited number of players within a single academy, meaning those conclusions may only apply to that academy alone, highlighting a need for similar analysis in larger, multi-club cohorts. Furthermore, this study focussed on injury burden (e.g. days missed due to injury) and did not report injury prevalence proportion (IPP) or injury incidence rate (IIR), which are equally important factors to be considered when investigating the effect of maturation in academy soccer players. Moreover, given the evidence that professional soccer match demands differ between countries (Dellal et al., 2011), it remains to be seen if injury risk differs between soccer academies from multiple countries

In light of the above, the aim of this study was to investigate whether maturity status (i.e. pre-, circa-, post-PHV or adult) was associated with injury risk in 501 male academy soccer players from eight individual academies in four different countries, thereby describing a larger and more diverse sample than any previous study in this area. We also aimed to investigate whether injury risk differed between countries. Based on recent evidence (Monasterio et al., 2020; Monasterio et al., 2021), we hypothesised that IPP, consequent 'days missed' and IIR would be greater after PHV (i.e. higher in post-PHV and adult compared to pre- and circa-PHV academy soccer players). We also hypothesised that there would be minimal differences in injury prevalence, incidence and consequent 'days missed' between post-PHV and adult academy soccer players.

Methods

Soccer injuries were prospectively recorded in 501 academy soccer players aged 9-23 years, registered to one of eight professional clubs from England (*n* = 5), Spain (*n* = 1), Uruguay (*n* = 1) and Brazil (*n* = 1). Of the English clubs, two were Category 1 (classified by the Premier League's Elite Player Performance Plan [EPPP] criteria), two were Category 2, and the final one was a talent development programme operating outside of the EPPP but competing regularly with Category 1 academies. The Uruguayan academy met the highest national standard (Category A). Despite no academy classification system in Spain or Brazil, those included in this study are amongst the most successful in their respective countries for producing elite professional players. To avoid the potential confounding issue of some players providing multiple seasons of injury data and others just one (Bult et al., 2018; Wik et al., 2020), each player contributed one season's injury record only, with 181 players for season 2014-15, 14 for 2016-17, and 306 for 2017-18. For each academy, the season with the most individual player records available was included for analysis. Written informed consent was obtained from club officials and players, with parental consent and player assent collected for participants under the age of consent for the respective country. Ethical approval was received from the University's ethics committee.

Body mass (kg) was measured on calibrated scales (Seca, Birmingham, UK). Standing and sitting height (m) were recorded via stadiometer and standardised anthropometry box (Holtain Limited, Crosswell, United Kingdom), respectively. Participants' maturity offset was estimated via a regression equation incorporating chronological age, body mass, standing height and sitting height to estimate years from PHV (Mirwald et al., 2002). Players were grouped according to maturity offset as pre-PHV (≤-1.0), circa-PHV (-0.5 to 0.5) and post-PHV (≥1.0). Players recording maturity offset between -1.0 to -0.5 or 0.5 to 1.0 were removed to account for the error in the Mirwald equation (~0.5 years)(Mirwald et al., 2002). One recent study segregated post-PHV academy players from those who have achieved full adult stature (Monasterio et al., 2021). We considered players with MO ≥ 4.0 as adult, based on evidence that males approach full adult height 3.5 years post-PHV (He & Karlberg, 2001). All players recording maturity offset between 3.5 and were 4.0 removed to account for the error in the Mirwald equation (Mirwald et al., 2002). Participant characteristics according to maturity status are described in Table 1. and Fig. 1 displays the proportions of players from each maturity status according to chronological age group.

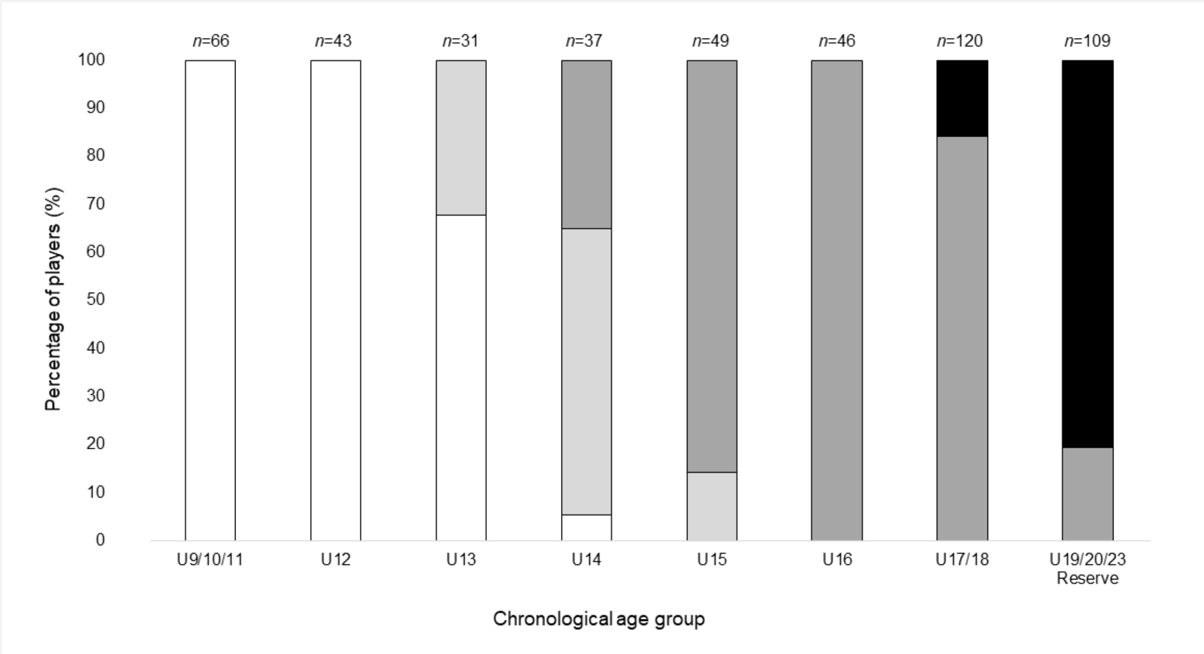

Fig 1. Relative contribution of maturity status [pre-PHV (white), circa-PHV (light grey), post-PHV (dark grey) and adult (black)] to each chronological age group.

Injury diagnosis and recording by club medics followed published guidelines (Fuller et al., 2006). Injuries were included if they had occurred during soccer-related activity and where a player was unable to participate in training or competition for ≥24 hours after injury incidence/onset. Players were considered injured until cleared to return to training and availability for match selection by club medics. 'Days missed' was the difference between the dates of injury and return to full training/availability. Only injuries sustained during the investigated season were analysed, meaning that if players began the season injured, existing injuries were not recorded. Injury history was unavailable for this study, with no players excluded on the basis of previous injury. Injuries were categorised based on those most frequently recorded in a previous injury audit for this cohort (Hall et al., 2020). Non-contact injuries were those without a clear incident involving contact with another player, the ball or another object, with each injury category including contact and non-contact injuries unless stated. Muscle and ligament/tendon injuries were investigated collectively as 'soft-tissue injuries' and also as separate categories due to different tissue structures and injury aetiology (Tozer & Duprez, 2005). Growth-related injuries refer to injuries diagnosed by medics as linked to somatic growth, including (but not limited to) Osgood Schlatter's disease and Sever's disease.

Participant characteristics are presented as mean ± standard deviation (SD). For each injury category, prevalence, absence and incidence were analysed. For each injury category, injury prevalence proportions (IPP) were calculated with 95% confidence intervals (Bueno et al., 2018), according to maturity status (i.e. pre-, circa- and post-PHV and adult, Table 1) and according to each country group (i.e. England, Spain, Uruguay and Brazil, Table 2). Binary logistic regression was used to determine the effects of maturity status and country on IPP (i.e. injured/not injured, referring to one or more injuries) for each injury category during a single season. The reference groups for comparisons of maturity status and country were 'pre-PHV' and 'England', respectively. Comparisons of days missed between groups only included those players, who had suffered at least one injury in that category, and were conducted by Kruskal-Wallis H test of variance, as the data were not normally distributed (therefore presented as median and interquartile range). Individual exposure minutes from training and matches were available for 166 academy soccer players from England (7.2%), Brazil (24.7%) and Spain (68.1%). Injury incidence rates (IIR) for these players are presented as number of injuries/1000 hours with 95% confidence intervals (Knowles et al., 2006). Incidences were calculated relative to total exposure (the sum of training exposure plus match exposure combined), because not all injury records specified whether an injury had occurred in training or a match. A generalised linear model assuming a Poisson distribution, with exposure hours as an offset representing time at risk, was used to derive rate ratios (RR) (reference group: post-PHV) with 95% confidence intervals for each injury category. Statistical significance was accepted at $p<0.05$. Statistical analyses were performed using RStudio (version 3.5.1) for comparisons of IPPs using binary logistic regression and IIRs by Poisson regression, and IBM SPSS version 25.0 (Armonk, NY, USA) for comparisons of days missed by Kruskal-Wallis H test of variance.

Results

A total of 323 injuries were recorded in the cohort of 501 players regardless maturity status, resulting in 8,560 days of absence (17.2 ± 38.9 per injury). Non-contact injuries accounted for 63.5% of all injuries. The most common types were muscle (30.3%), ligament (24.1%) and growth-related injuries (11.5%), while the thigh (23.8%), knee (22.0%) and ankle (14.9%) the most common locations.

Injury prevalence proportion (IPP) according to maturity status is presented in Table 1. When combining all injuries, IPP increased with advancing maturity. Specifically, circa-PHV, post-PHV and adult each had higher IPP than pre-PHV ($p=0.032$, $p<0.001$ and $p<0.001$, respectively). For non-contact injuries, IPP was higher in post-PHV and adult than pre-PHV ($p=0.001$ and $p=0.012$, respectively), with no difference between pre- and circa-PHV. Similarly, IPP was greater in post-PHV and adult than pre-PHV for soft-tissue injuries ($p<0.001$ and $p<0.001$, respectively) and non-contact soft-tissue injuries ($p<0.001$ and $p=0.005$, respectively), with no difference between pre- and circa-PHV for either category. The IPP for muscle injuries was greater in post-PHV and adult than pre-PHV (both $p<0.001$), with no difference between pre- and circa-PHV. For ligament/tendon injuries, IPP was greater in adult versus pre-PHV ($p=0.002$). Thigh IPP was greater in post-PHV and adult compared to pre-PHV ($p<0.001$ and $p<0.001$, respectively), with no difference versus pre-PHV. Ankle IPP was higher in post-PHV and adult versus pre-PHV ($p=0.035$ and $p=0.007$, respectively), whilst hamstring IPP was greater in post-PHV and adult than pre-PHV ($p=0.041$ and $p=0.017$, respectively). The IPP for growth injuries was lower in post-PHV than pre-PHV ($p=0.039$), with no difference between pre- and circa-PHV, and no growth-related injuries were recorded in adult players. Where there was a significant effect of maturity status for a particular injury category, odds ratios (OR) were also higher for those maturity groups that had a higher IPP than pre-PHV (Table 1).

To investigate whether this pattern of increasing IPP with advancing maturity was evident in all four countries, binary logistic regression analysis (with maturity status as the sole independent factor) was performed within each country separately. For England, the IPP (95% CI) for all injuries combined was higher for circa-PHV [50.0 (25.5 – 74.5), p=0.021], post-PHV [53.5 (41.9 – 65.1), p<0.001] and adult [51.0 (37.3 – 64.7), p<0.001] compared to pre-PHV [20.6 [11.0 – 30.2)]. For Spain, IPP for all injuries combined was higher for post-PHV [70.4 (53.1 – 87.6), p=0.016] and adult [76.2 (58.0 – 94.4), p=0.010] compared to pre-PHV [42.3 (30.1 – 54.3). For Brazil, IPP in adult players was non-significantly higher than post-PHV [40.0 (9.6 – 70.4) *vs.* 29.4 (14.1 – 44.7)] and for Uruguay, adult had the highest IPP of all groups [32.0 (13.7 – 50.3)], but was not significantly different to the IPP of the other groups.

Binary logistic regression analysis also revealed differences in IPP between countries (Table 2). Compared to England, Spain had a higher IPP for all injuries combined (p=0.015), non-contact (p<0.001), muscle (p=0.044), non-contact soft-tissue (p<0.001), growth-related (p<0.001), low back/sacrum/pelvis (p<0.001), thigh (p<0.001) and hamstring (p<0.001). Conversely, Uruguay had a lower IPP versus England for all injuries combined (p<0.001), non-contact (p=0.001), soft-tissue (p=0.002), muscle (p=0.001) and non-contact soft-tissue (p<0.001). Similarly, Brazil had a lower IPP for all injuries combined (p=0.025) and knee injuries (p=0.043) compared to England. Where there was a significant effect of country for a particular injury category, odds ratios (OR) were also higher/lower for those countries that had a higher/lower IPP compared to England (Table 2).

As participants were recruited from five different academies in England and only from one academy in each of the three remaining countries, we performed additional binary logistic regression analyses solely including those five English academies regarding all injuries combined. Accordingly, the IPP (95% CI) for all injuries combined was higher for academy 1 [57.5 (43.3 – 71.6)] than for academy 2 [35.6 (21.6 – 49.5), p=0.037], for academy 3 [32.8 (20.7 – 44.8), p=0.012], for academy 4 [31.0 (17.0 – 44.9), p=0.013] but not for academy 5 [78.6 (57.1 – 100.1), p=0.162]. Thus, differences in IPP for all injuries combined existed between multiple academies within the same country.

Days missed

For players recording one or more soft-tissue injuries, the cumulative days missed due to that injury category was greater in post-PHV (22 (26) days, p=0.029) and adult (23 (38) days, p=0.007) than pre-

PHV (12 (12) days). There were no associations between maturity status and days missed regarding any other injury category (Table 3).

Injury incidence rates (IIR)

Incidence rates for a large sub-sample of academy players with exposure records available (*n*=166) are presented in Table 4. General IIR was lower for pre-PHV than post-PHV (RR = 0.53 (0.36 – 0.79), p=0.002). Non-contact IIR was lower for pre-PHV (RR = 0.56 (0.37 – 0.84), p=0.006), circa-PHV (RR = 0.49 (0.25 – 0.88), p=0.026) and adult (RR = 0.61 (0.39 – 0.93), p=0.024) than post-PHV. Soft-tissue IIR was lower for pre-PHV (RR = 0.23 (0.11 – 0.44), p<0.001) and circa-PHV (RR = 0.19 (0.05 – 0.53), p=0.006) than post-PHV. Non-contact soft-tissue IIR was lower for pre-PHV (RR = 0.61 (0.40 – 0.92), p=0.018) and adult (RR = 0.64 (0.41 – 0.99), p=0.047) than post-PHV. Muscle IIR was lower for pre-PHV (RR = 0.11 (0.03 – 0.31), p<0.001) and circa-PHV (RR = 0.20 (0.03 – 0.69), p=0.032) than post-PHV. Similarly, thigh IIR was lower for pre-PHV (RR = 0.15 (0.04 – 0.40), p<0.001) and circa-PHV (RR = 0.11 (0.01 – 0.51), p=0.029) than post-PHV. The incidence of growth-related injuries was higher for pre-PHV (RR = 5.8 (2.01 – 24.49), p=0.004) and circa-PHV (RR = 4.5 (1.19 – 21.32), p=0.034) compared to post-PHV. There were no growth-related injuries recorded for adult academy players.

Table 1. Participant characteristics and injury prevalence proportion (IPP, i.e. % players injured) with 95% confidence intervals (CI) plus odds ratios (OR) with 95% CI for each injury category, according to maturity status [Pre-/Circa-/Post-peak height velocity (PHV)/Adult].

	Pre-PHV†	**Circa-PHV**		**Post-PHV**		**Adult**	
n (% cohort)	132 (26.3)	39 (7.8)		223 (44.5)		107 (21.4)	
Age (y)	11.2 ± 1.2	13.8 ± 0.6		16.7 ± 1.4		19.6 ± 1.4	
Height (m)	1.47 ± 0.07	1.67 ± 0.05		1.76 ± 0.06		1.83 ± 0.07	
Mass (kg)	37.1 ± 4.8	53.8 ± 4.4		69.4 ± 7.4		78.4 ± 7.5	
Maturity offset (y)	-1.6 ± 1.3	0.2 ± 0.5		2.4 ± 0.8		4.7 ± 0.8	
Injury category	**IPP (95% CI)**	**IPP (95% CI)**	**OR (95% CI)**	**IPP (95% CI)**	**OR (95% CI)**	**IPP (95% CI)**	**OR (95% CI)**
All injuries combined	31.1 (23.2 – 39.0)	43.6 (28.0 – 59.2)*	2.4 (1.1 – 5.2)	35.3 (29.0 – 41.6)*	3.5 (2.0 – 6.1)	50.5 (41.0 – 60.0)*	4.8 (2.7 – 8.8)
Non-contact	25.8 (18.3 – 33.3)	28.2 (14.1 – 42.3)	1.5 (0.6 – 3.4)	26.7 (20.9 – 32.5)*	2.9 (1.6 – 3.4)	29.0 (20.4 – 37.6)*	2.5 (1.3 – 4.9)
Soft-tissue	16.7 (10.3 – 23.1)	20.5 (7.8 – 33.2)	1.5 (0.6 – 3.5)	32.1 (26.0 – 38.2)*	3.8 (2.1 – 7.0)	40.2 (30.9 – 49.5)*	4.5 (2.4 – 8.6)
Muscle	6.1 (2.0 -10.2)	10.3 (0.8 – 19.8)	2.1 (0.5 – 7.2)	19.0 (13.9 – 24.1)*	7.8 (3.5 – 19.4)	21.5 (13.7 – 29.3)*	6.8 (2.9 – 17.5)
Ligament/tendon	10.6 (5.3 – 15.9)	10.3 (0.8 – 19.8)	1.0 (0.3 – 3.0)	16.3 (11.5 – 21.1)	1.9 (0.9 – 3-9)	26.2 (17.9 – 34.5)*	3.2 (1.6 – 6.8)
Non-contact soft-tissue	25.8 (18.3 – 33.3)	28.2 (14.1 – 42.3)	1.5 (0.6 – 3.5)	26.7 (20.9 – 32.5)*	3.1 (1.7 – 5.8)	28.0 (19.5 – 36.5)*	2.3 (1.2 – 4.4)
Growth-related	15.2 (9.1 -21.3)	12.8 (2.3- 23.3)	0.9 (0.3 – 2.8)	1.8 (0.1 – 3.5)	0.3 (0.1 – 0.8)	0.0 (-)	0.0 (-)
Low back/sacrum/pelvis	9.1 (4.2 – 14.0)	7.7 (0.7 – 16.1)	0.9 (0.2 – 3.5)	5.0 (2.1 – 7.9)	2.1 (0.8 – 5.7)	1.9 (0.7 – 4.5)	0.4 (0.1 – 1.7)
Knee	11.4 (6.0 – 16.8)	12.8 (2.3 – 23.3)	1.2 (0.4 – 3.4)	12.7 (8.3 – 17.1)	1.6 (0.8 – 3.4)	16.8 (9.7 – 23.9)	2.0 (0.9 – 4.3)
Ankle	3.9 (0.6 – 7.2)	10.3 (0.8 – 19.8)	3.2 (0.8 – 12.9)	7.7 (4.2 – 11.2)*	3.2 (1.2 10.5)	12.1 (5.9 – 18.3)*	4.5 (1.6 – 14.7)§
Thigh	3.8 (0.5 – 7.1)	5.1 (1.8 – 12.0)	1.6 (0.2 – 7.8)	13.1 (8.7 – 17.5)*	7.1 (2.7 – 22.9)	17.8 (10.6 – 25.0)*	9.2 (3.3 – 30.0)
Hamstring muscle	3.8 (0.5 – 7.1)	2.6 (2.4 – 7.6)	0.7 (0.0 – 4.9)	5.9 (2.8 – 9.0)*	3.4 (1.9 – 11.7)	8.4 (3.1 – 13.7)*	4.2 (1.3 – 14.9)

†*Reference group = Pre-PHV; *different versus Pre-PHV (p < 0.05).*

Table 2. Participant characteristics, injury prevalence proportion (IPP, i.e. % players injured) with 95% confidence intervals (CI) plus odds ratios (OR) with 95% CI, according to country of academy.

	England[†]	Spain		Uruguay		Brazil	
n (% cohort)	206 (41.1)	128 (25.5)		123 (24.6)		44 (8.8)	
Age (y)	15.5 ± 3.6	14.0 ± 3.6		16.8 ± 1.8		18.0 ± 1.2	
Height (m)	1.68 ± 0.17	1.62 ± 0.17		1.75 ± 0.07		1.79 ± 0.08	
Mass (kg)	59.9 ± 18.3	51.2 ± 16.2		70.6 ± 8.8		74.5 ± 9.1	
Injury category	**IPP (95% CI)**	**IPP (95% CI)**	**OR (95% CI)**	**IPP (95% CI)**	**OR (95% CI)**	**IPP (95% CI)**	**OR (95% CI)**
All injuries combined	41.8 (35.0 – 48.5)	55.5 (46.9 – 64.1)*	2.4 (1.5 4.0)	15.5 (9.1 – 21.8)*	0.2 (0.1 – 0.3)	31.8 (18.1 – 45.6)*	0.4 (0.2 – 0.9)
Non-contact	22.3 (16.6 – 28.0)	50.8 (42.1 – 59.4)*	4.7 (2.9 – 8.2)	10.6 (5.1 – 16.0)*	0.3 (0.1 – 0.5)	29.6 (16.1 – 43.0)	1.1 (0.5 – 2.3)
Soft-tissue	32.0 (25.7– 38.4)	29.7 (21.8 – 37.6)	1.2 (0.7 – 2.0)	22.8 (15.4 – 30.2)*	0.4 (0.3 – 0.7)	27.3 (14.1 – 40.4)	0.5 (0.2 – 1.1)
Muscle	17.0 (11.9 -22.1)	20.3 (13.3 -27.3)*	1.9 (1.0 – 3.5)	8.1 (3.3 – 13.0)*	0.3 (0.1 – 0.6)	13.6 (3.5 – 23.8)	0.5 (0.2 – 1.1)
Ligament/tendon	17.5 (12.3 – 22.7)	14.8 (8.7 -21.0)	1.0 (0.5 – 1.8)	16.3 (9.7 – 22.8)	0.8 (0.4 – 1.5)	15.9 (5.1 – 26.7)	0.7 (0.3 – 1.8)
Non-contact soft-tissue	21.4 (15.8 – 27.0)	50.0 (41.3 – 58.7)*	4.8 (2.9 – 8.1)	9.8 (4.5 – 15.0)*	0.3 (0.2 – 0.6)	27.3 (14.1 – 40.4)	0.9 (0.4 – 1.9)
Growth-related	1.5 (0.2 -3.2)	19.5 (12.6 - 26.4)*	13.1 (4.4 – 56.5)	0.8 (0.0 – 2.4)	0.1 (0.1 – 9.9)	0.0 (-)	0.0 (-)
Low back/sacrum/pelvis	0.5 (0.2 – 1.4)	19.5 (12.7 – 26.4)*	56.3 (11.3 – 102)	1.6 (0.6 – 3.9)	2.5 (0.2 – 5.4)	0.0 (-)	0.0 (-)
Knee	14.1 (9.3 – 18.8)	15.6 (9.3 -21.9)	1.3 (0.7 – 2.4)	13.0 (7.1 – 19.0)	0.8 (0.4 – 1.6)	2.3 (1.2 – 6.7)*	0.1 (0.0 – 0.6)
Ankle	9.2 (5.3 – 13.2)	8.6 (3.7 – 13.4)	1.1 (0.5 – 2.5)	5.7 (1.6 – 9.8)	0.5 (0.2 – 1.1)	4.6 (1.6 -10.7)	0.4 (0.1 – 1.4)
Thigh	7.3 (3.7 – 10.8)	17.2 (10.7 – 23.7)*	4.2 (2.0 – 9.1)	7.3 (2.7 11.9)	0.7 (0.3 – 1.7)	20.5 (8.5 – 32.4)	2.2 (0.8 – 5.4)
Hamstring muscle	2.9 (0.6 – 5.2)	11.7 (6.1 – 17.3)*	6.0 (2.3 – 17.8)	4.1 (0.6 -7.6)	1.1 (0.3 – 3.8)	4.6 (1.6 -10.7)	1.2 (0.2 – 5.3)

[†]*Reference group = England; *different versus England ($p < 0.05$).*

Table 3. Total days missed per injured player for each injury category according to maturity status (pre-PHV, circa-PHV, post-PHV and adult), expressed as median (interquartile range).

Injury category	**Pre-PHV**	**Circa-PHV**	**Post-PHV**	**Adult**	**Total Days**
	n = 132	*n* = 39	*n* = 223	*n* = 107	
General	15 (33)	29 (65)	46 (44)	49 (56)	8,560
Non-contact	17 (28)	19 (49)	25 (38)	22 (60)	5,326
Soft-tissue	12 (12)	14 (22)	22 (26)*	23 (38)*	4,586
Muscle	10 (24)	15 (67)	14 (25)	17 (16)1	1,682
Ligament/tendon	13 (12)	24 (42)	27 (30)	27 (40)	3,302
Non-contact soft-tissue	17 (28)	19 (30)	24 (25)	21 (59)	4,260
Growth-related	15 (18)	19 (19)	10 (8)	0 (0)	686
Low back/sacrum/pelvis	17 (21)	65 (25)	61 (81)	8 (10)	1,221
Knee	16 (28)	8 (16)	24 (33)	29 (58)	2,950
Ankle	15 (19)	33 (20)	30 (41)	24 (32)	1,352
Thigh	19 (38)	14 (21)	15 (25)	19 (40)	1,411
Hamstring muscle	19 (38)	0 (0)	13 (32)	18 (33)	695

**Significantly higher than pre-PHV ($p < 0.05$).*

Table 4. Frequency and incidence of injuries according to maturity status [Pre-/Circa-/Post-peak height velocity (PHV)/Adult] in a sample of academy soccer players with exposure records (*n* = 166).

	Pre-PHV		**Circa-PHV**		**Post-PHV**		**Adult**	
n (% cohort)	52 (31)		16 (10)		57 (34)		41 (25)	
Exposure (hours)								
Total	10,506		3,693		8,306		8,201	
Training	9,090		3,070		5,294		6,590	
Match	1,416		623		3,012		1,611	
Injury category	**Frequency**	**IIR (95% CI)**	**Frequency**	**IIR (95% CI)**	**Frequency**	**IIR (95% CI)**	**Frequency**	**IIR (95% CI)**
All injuries combined	41	3.90 (2.71 – 5.10)*	17	4.60 (2.41 – 6.79)	61	7.34 (5.50 – 9.19)	57	6.95 (5.15 – 8.75)
Non-contact	40	3.81 (2.63 – 4.99)*	14	3.79 (1.81 – 5.78)*	55	6.62 (4.87 – 8.37)	33	4.02 (2.65 – 5.40)*
Soft-tissue	10	0.95 (0.36 – 1.54)*	3	0.81 (-0.11 – 1.73)*	35	4.21 (2.82 – 5.61)	29	3.54 (2.25 – 4.82)
Muscle	3	0.29 (-0.04 – 0.61)*	2	0.54 (-0.21 – 1.29)*	22	2.65 (1.54 – 3.76)	19	2.32 (1.27 – 3.36)
Ligament/tendon	7	0.67 (0.17 – 1.16)	2	0.54 (-0.21 – 1.29)	12	1.44 (0.63 – 2.26)	12	1.46 (0.64 – 2.29)
Non-contact soft-tissue	39	3.81 (2.55 – 4.88)*	12	3.25 (1.21 – 5.09)	52	6.26 (4.56 – 7.96)	33	4.02 (2.65 – 5.40)*
Growth-related	22	2.09 (1.22 – 2.97)*	6	1.62 (0.32 – 2.92)*	3	0.36 (-0.05 – 0.77)	0	0.00 (0.00 – 0.00)
Low back/sacrum/pelvis	13	1.24 (0.56 – 1.91)	5	1.35 (0.17 – 2.54)	15	1.81 (0.89 – 2.72)	1	0.12 (-0.12 – 0.36)
Knee	11	1.05 (0.43 – 1.67)	2	0.54 (-0.21 – 1.29)	9	1.08 (0.38 – 1.79)	8	0.98 (0.30 – 1.65)
Ankle	3	0.29 (-0.04 – 1.67)	3	0.81 (-0.11 – 1.73)	4	0.48 (0.01 – 0.95)	7	0.85 (0.22 – 1.49)
Thigh	4	0.38 (0.01 – 0.75)*	1	0.27 (-0.26 – 0.80)*	21	2.53 (1.45 – 3.61)	22	2.68 (1.56 – 3.80)
Hamstring muscle	4	0.38 (0.01 – 0.75)	1	0.27 (-0.26 – 0.80)	10	1.20 (0.46 – 1.95)	9	1.10 (0.38 – 1.81)

†*Reference group = Post-PHV; IIR, injury incidence rate (number of injuries per 1000 hours' exposure); CI, confidence intervals; *different versus Post-PHV (p < 0.05).*

Discussion

This is the first multi-academy and multi-national study to investigate the association of maturity status with injury risk in over 500 academy soccer players. In line with our primary hypothesis, the main findings were that injury prevalence proportion (IPP) was highest in biologically mature academy soccer players. Specifically, the IPP of all injuries combined, non-contact injuries, soft-tissue injuries, muscle injuries, thigh injuries, hamstring muscle injuries and ankle injuries were each highest in post-PHV and adult players. Furthermore, differences in IPP existed between academies from different countries but, crucially, the overall pattern of increasing IPP with advancing maturity status was evident across countries. Moreover, the patterns of IPP (in n = 501) and injury incidence rate (IIR, in n = 166) were broadly similar, in that both were generally higher in post-PHV and adult academy players, which was in agreement with our secondary hypothesis. Our data highlight the types and locations of injuries that require most attention in academy soccer players at different stages of maturation, which has important implications when considering maturity-specific injury prevention strategies in this population.

There are several potential explanations for a higher IPP and IIR of specific injuries in adult and post-PHV academy players than pre- and circa-PHV. In comparable populations, older players experience greater training volumes (Read et al., 2017) and play more regular matches with faster and more aggressive playing styles, involving greater risk-taking behaviours (Keller et al., 1988). In our sub-sample of players with exposure records (n = 166), although the post-PHV players had lower overall exposure than the other maturity groups, their ratio of match to training exposure was higher. Thus, considering injuries typically occur more often during competition (Bult et al., 2018), a greater proportion of match exposure may increase injury risk due to an increased frequency of high intensity activities. The need for rest and recovery due to regular exposure to match activity may also reduce the ability for players to undertake sufficient training volumes that might protect against injury. Together, the combination of these factors may contribute to the higher IIR for certain injuries in this group. As expected, post-PHV and adult players had larger body mass than pre- and circa-PHV (likely due to the testosterone-induced increase in lean mass that occurs during maturation) (Albin & Norjavaara, 2013) and, when combined with fast and aggressive playing styles (Keller et al., 1988), greater mass will produce more momentum and may lead to players losing control. In turn, this may increase collision forces (Figeuiredo et al., 2010) and contact injury risk, as well as the risk of non-contact injury if extensive stress is placed on ligaments and/or the muscle-tendon unit during rapid deceleration or change of direction (Alentorn-Geli et al., 2009). Accordingly, anthropometric differences that can favour mature players when executing speed and strength during competition (Malina et al., 2005) might actually increase the same players' risk of injury.

The playing history of post-PHV and adult academy players compared to biologically younger players may also contribute to our findings, because injury risk increases as players accumulate multiple seasons of training and competition throughout their careers (Alentorn-Geli et al., 2009), with previous injury increasing the risk of subsequent injury (Ekstrand & Gillqvist, 1983). Therefore, some injuries recorded in this study are potentially linked to previous injuries, though injury history was not available to support or refute this hypothesis. If post-PHV and/or adult players in this study suffered recurrent injuries, this could contribute to our finding that those players missed more days to soft-tissue injuries than pre-PHV. Injury risk is also associated with congested fixture schedules (Dupont et al., 2010), suggesting insufficient recovery between intense competition increases the risk of musculoskeletal injury. Ligaments and tendons heal slower than skeletal muscle (probably due to lower vascularisation) (Tozer & Duprez, 2005), with chronic inflammation (e.g. due to insufficient rest and recovery) leading to weakness and functional impairment (Tozer & Duprez, 2005). Accordingly, the association of post-PHV and adult maturity status with the higher IPP and IIR of soft-tissue injuries might relate to inadequate recovery of overloaded tissues during demanding soccer schedules.

Our main findings broadly support our primary hypothesis that the post-PHV and adult maturity groups, where players are chronologically older, would be associated with higher IPP and IIR than the pre- and circa-PHV groups. Other studies that included multiple clubs reported an increase in injuries with advancing age in similar populations (Price et al., 2004; Read et al., 2017), although others have suggested that injury risk is acutely augmented as players undergo PHV (Bult et al., 2018; Johnson et al., 2020; Van der Sluis et al. 2015). We found that relatively more post-PHV and adult players suffered injuries than pre- and circa-PHV players, which was supported by our sub-sample, for whom IIR data were calculated (i.e. accounting for training and match exposure). This suggests that players, who have *surpassed* PHV, rather than those *undergoing* PHV, are at greater risk of injury (except for growth-related injuries). In our data, this was the case when combining all injuries, highlighting the importance of considering growth-related injuries separately in this population. As anticipated, the IPP and IIR of growth-related injuries were higher in pre- and circa-PHV than post-PHV (none recorded in adult players). This is probably due to biologically older players having surpassed peak growth and being less likely to experience growth-related injuries. However, similarities in the IPP and IIR of growth-related injury between pre- and circa-PHV players suggest that, whilst somatic growth does appear to be associated with injury susceptibility, pre-PHV players should be considered equally 'at risk' of growth-related injuries as players who are circa-PHV. Monitoring lower extremity growth on a regular basis and reducing soccer training load during periods of rapid growth may help prevent growth-related injuries (Rommers et al., 2020). This could be combined with extended recovery/rest and/or non-impact activities, such as swimming and cycling, made available to maintain cardiovascular fitness without exacerbating existing symptoms (Circi et al., 2017). Accordingly, injury prevention strategies in academy soccer should consider maturity status when addressing growth-related injuries, yet remain cognisant of a well-documented and general increase in injuries with advancing chronological age (Price et al., 2004).

While other studies have investigated a single academy (Bult et al., 2018; Johnson et al., 2020; Monasterio et al., 2020; Monasterio et al., 2021; Van der Sluis et al., 2014; Van der Sluis et al., 2015), or one country (Le Gall et al., 2007; Read et al., 2017), our study is the first to recruit a large cohort from multiple high-level academies in numerous clubs and countries, rather than presenting less generalisable data from a single club setting. This strengthens the external validity of our findings, which improve current understanding of how maturation influences injury in academy soccer. This study is only the second to differentiate between and compare post-PHV and adult academy players (Monasterio et al., 2021), but it is the first to investigate differences in IPP and IIR between post-PHV and adult academy players and, crucially, it is the first to do so in a larger sample of players from more than one academy. We acknowledge the greatest proportion of academies (and therefore participants) were based in England and it could be assumed that the greater proportion of participants coming from England might have biased our results. However, our between country analyses (Table 2) revealed that

Spain had a larger IPP regarding most injury categories compared to England (despite England and Spain providing a similar proportion of pre-, circa-, post-PHV and adult participants), and Uruguay and Brazil a smaller IPP compared to England regarding just two-to-four injury categories (despite Spain and Uruguay providing a similar absolute number of participants). In spite of these differences in IPP between countries, the pattern of injury we observed in IPP for our full cohort, and for IIR in our sub-sample, was consistent in the pattern of IPP observed in each country separately (i.e. an increase in IPP with advancing maturity). In academies from both England and Spain, post-PHV and adult players had higher IPP relative to pre-PHV when combining all injuries, with no difference between pre- and circa-PHV. Post-PHV and adult also had the greatest IPP in Uruguay though this was non-significant, likely due to a low number of circa-PHV players. Our Brazilian academy contributed the smallest number of players to the study overall, and comprised only post-PHV and adult, though IPP was again highest in the more mature players. Moreover, we also observed differences in IPP between the five English academies. Thus, it would be imprudent to suggest that the between country differences in IPP we observed were due to 'country-specific' differences in data recording, governance structures, training training/match demands, playing styles, recovery/injury prevention strategies, etc. However, it is possible that differences in such factors do exist between academies, regardless of country of origin, and that these may influence injury risk. To record and control for such factors when collecting data in high-level sporting environments is, however, particularly challenging. Nevertheless, including academies from multiple countries/continents enables our data to be much more widely applicable than previous studies. Further, our novel associations suggest the relationship between maturity status and injury depends on both the type and location of injury, highlighting the merit of including such details when recording injuries for surveillance studies. Additionally, despite the IPP and IIR of some injuries differing between post-PHV and adult academy soccer players, the injuries suffered between these two groups were broadly similar, in agreement with recent findings (Monasterio et al., 2020; Monasterio et al., 2021). Importantly, however, both groups generally had a higher IPP and IIR compared to pre- and circa-PHV players.

As well as the aforementioned strengths, we acknowledge certain limitations with our study. Firstly, we estimated PHV rather than use direct measurement. However, this permitted the noninvasive measurement of over 500 players. We also recognise the potential importance of peak weight velocity and acknowledge the omission of such measures. To account for the ~0.5 year error in the equation (Mirwald et al., 2002), we excluded players with a maturity offset between -1.0 to -0.5 years (distinguishing pre- from circa-PHV) or 0.5 to 1.0 years (distinguishing circa- from post-PHV). Likewise, players recording a maturity offset between 3.5 and 4.0 years were removed to provide a clear distinction between post-PHV and adult. We also recognise that fewer circa-PHV players were recruited than pre-PHV, post-PHV and adult. However, this is due to the short period of time, during which PHV occurs (<12 months), compared to pre- and post-PHV, as well as adult categories (≥3.5 years). Despite including all injuries per player during a single season, we were unable to determine whether our injury data had been influenced by previous injury. However, to do this with confidence, complete injury history is necessary, which was not available for all players. In recent studies that benefitted from longitudinal data, injury history was not a key consideration, and confidently linking current and previous injuries is likely to be complex. We also acknowledge that documenting specific muscles, ligaments and tendons, and subclassification of different growth-related injuries, would provide greater insight, and we recommend this for future studies. In addition, exposure records were limited to 33% (*n*=166) of our total sample (*n*=501). We could have estimated exposure on a group basis as has been done elsewhere (Materne et al., 2020), however, this fails to account for differences between players and underestimates injury incidence (Stovitz et al., 2020). This informed our rationale to only report IIRs in players for whom individual exposure minutes were recorded, and we acknowledge that this approach led to lower numbers of injuries for certain categories, potentially limiting the ability to detect statistically significant differences in IIRs. Nonetheless, our sub-sample contains more individual academy players than some previously published reports (Johnson et al., 2020, Monasterio et al., 2020; Monasterio et al., 2021; Van der Sluis et al., 2014, Van der Sluis et al., 2015) and, crucially, the maturity-dependent differences in IIR we observed generally reflected the maturity group differences in IPP and days missed observed in the total cohort.

Conclusions

This study is the largest of its kind to investigate the effect of maturity status on injury risk in academy soccer players, incorporating eight academies from four countries. While injury prevalence proportion (IPP) varied between academies from different countries, our data demonstrate that IPP was generally higher in post-PHV and adult male academy soccer players compared to pre- and circa-PHV. Importantly, this overall pattern of increasing IPP with advancing maturity status was evident across countries. Injury incidence rates (IIR) from a sub-sample (*n* = 166) of our total cohort (*n* = 501) support these findings, suggesting that IPP may be used as a surrogate of IIR when investigating the effect of maturity status on injury risk in male academy soccer players. Compared to pre- and circa-PHV, relatively more post-PHV and adult players suffered soft-tissue, muscle and thigh injuries and missed more days during one season to soft-tissue injuries. We suggest that injury prevention strategies in academy soccer should be designed according to the players' maturity status and the associated injury types/locations reported in this study. Specifically, targeted strength, conditioning and recovery practices may be particularly beneficial to post-PHV and adult players, with the specific aim of reducing soft-tissue injuries and injuries to the thigh and ankle, and that pre- and circa-PHV players may benefit from monitoring strategies aimed at reducing any deleterious consequences of acute changes in lower limb length by identifying peak growth periods.

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