Does early specialization provide an advantage in physical fitness development in youth basketball?

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ABSTRACT

Background: Early specialization is often assumed to promote quicker and better physical development to attain expertise in sports. This study examined the influence of the specialization onset on the magnitude and patterns of changes in basketball-specific physical fitness within a competitive season, and developmental trends of fitness between 11-17 years in young basketball players. The prior hypothesis was that young basketball players who specialize before pubertal growth (early) would have better physical fitness and develop faster than those who specialize during or after the pubertal growth period. We examined repeated measures of 181 young basketball players (female, n=40; male, n=141). Anthropometry, age, estimated maturity status, and basketball-specific physical fitness (assessed with the countermovement jump, line drill, and yo-yo intermittent recovery level-1 and fitness score) were considered. We grouped players by the onset of specialization as related to biologic maturation milestones (pre-puberty, mid-puberty, and late-puberty specialization). The within-season and developmental changes in physical fitness were fitted using multilevel modeling in a fully Bayesian framework. The fitness outcomes were similar between-player and within-player changes when grouped by specialization across a season. Fitness improvements across a season were apparent for female players, while male players maintained the performance levels. There was no variation in the patterns of physical fitness development between 11-17 years associated with the onset of specialization. Conditional on our data and models, the

assumption that early sport specialization provides a physical fitness advantage for future athletic success does not hold. Relevant stakeholders should be conservative in the expectations of development and improvements of physical fitness across a season and adolescence in young basketball players. We provide an operational framework to interpret specialization related to biological maturation milestones.

INTRODUCTION

The notion that early sport specialization is essential for performance development and attainment of expertise is deeply entrenched in youth sports [1]. The notion has been based on the deliberate practice theory [2] applied to sports [3-5]. An underlying premise of the theory applied to sports is that highly specific training with appropriate supervision at an early age will improve the functioning of the body's main organ systems, beyond what normal growth and development or more diversified physical activities can achieve [6]. Unfortunately, however, clear evidence is virtually nonexistent to address whether there is a physiological advantage of early specialization.

The debate about the merits and risks of specialization in youth sports has recently increased [7-12]. Specialization, in general, can be conceptualized as year-round participation in a single "signature" sport, with limited participation in potential sport alternatives, with a deliberate focus on training and development in the pursuit of elite status [10, 13-15]. Youth sports participation and specialization can be conceptualized as a continuum, but there are no clear references for early or late specialization [9, 14]. An important caveat remains, given the lack of consensus about the definition of early specialization [9]. We argue that specialization can be defined and interpreted relative to pubertal growth [4, 14]. Specifically, we can consider the onset of specialization as related to biological maturation milestones that describe the pubertal growth period, i.e., the age of initiation of the pubertal growth spurt and the age at peak height velocity (PHV). Based on growth studies data [16], the biological maturation milestones can be defined using meta-analysis [14]. Players can be labeled as follows: pre-puberty specialization, when specialization occurs before the onset of pubertal growth (i.e., early specialization); mid-puberty, when specialization occurs between the onset of pubertal growth and the age of PHV (i.e., during pubertal growth); late-puberty specialization, when specialization occurs after pubertal growth (i.e., after the age of PHV).

In this study, we focus on youth basketball. Coaches and youth basketball programs generally promote engagement and commitment to basketball practice in supervised training contexts as early as five years of age [17]. In basketball, body dimensions and specific physical fitness, including vertical jump, sprints with direction changes, and intermittent endurance, are important determinants of performance at high competitive levels [18]. Consequently, decisions

of selection/promotion in youth basketball are substantially influenced by players' physical fitness and size. On the other hand, the partition of maturity-associated in body size and physiological functions is warranted to interpret appropriately young players' performance [19, 20]. However, the increased observations in youth basketball continue to be mostly based on cross-sectional surveys [14, 19, 21-23], despite the persistent call for longitudinal designs.

Coaches generally expect fitness to be maintained or improved during a season and across adolescence [24]. Therefore, understanding the development patterns across a competitive season and adolescence may provide valuable information to coaches and stakeholders to elevate the quality of their training interventions and decision-making, especially at early ages. Unfortunately, however, data analyzing physical fitness responses across a competitive season and during adolescence among young basketball players is limited [20, 24, 25]. Furthermore, sexual dimorphism with pubertal growth may complicate the interpretations about the influence of specialization on physical fitness development in youth basketball. Sex differences in timing and tempo of pubertal growth and maturation are substantial [16], and merit consideration when examining the physical fitness development of adolescent basketball players

We focus on examining the validity of the assumption supporting early specialization, stating that there are basketball-specific physical fitness advantages of early specialization in young players [1, 6]. Hence, we examined the influence of the specialization onset on the magnitude and patterns changes in basketball-specific physical fitness within a competitive season, and in the developmental trends of fitness from 11 to 17 years in young basketball players. To allow a comprehensive interpretation, we illustrate the use of multilevel modeling in a fully Bayesian framework to estimate the variation in the outcomes accounting for repeated measures and cross-classified nesting, i.e., within players' variation across the season and between player variation in the physical fitness changes responses by the onset of specialization, sex, competitive age group, and estimated maturity status.

METHOD

Participants and study design

This study considered data from surveys with repeated measures data collected from competitive seasons from 2015 to 2019 in youth basketball. The sample included 181 youth basketball players (female players, n = 40; male players, n = 141) aged between 11.7 and 17.0 years at pre-season. Specifically, in this study, we considered repeated measures across a competitive season of players from under-13, under-15, and under-17 teams at pre-season (February/March), mid-season (July/August), and at end-season (November/December). The players were measured and tested within a week in each observation period. From the total sample, 53, 105, and 53 under-13 players completed observations at pre-, mid-, and end-season, respectively; 67, 102, and 43 under-15 players completed observations at pre-, mid-, and end-season, respectively; 31, 32, and 23 under-17 players completed observations at pre-, mid-, and end-season, respectively.

Hence a total of 509 measurements were considered. In addition, data from consecutive seasons were grouped by season to adjust for variation between seasons in the outcomes of interest.

Players were engaged in formal youth basketball training programs and competed in the state-level competition supervised by the local federation. All subjects trained at least three times a week (1.5 – 2.5 hours/training day) and played a match most of the weekends over a 9-month competitive season. No players reported moderate or more severe injuries during 6-months before the testing. We grouped players into five age categories (under-13, under-15, and under-17), according to their birth date to the respective year of assessment (for example, a player who would complete 13 years was classified as under-13, while a player who would complete 14 years in the same season was classified as under-15). The state basketball federations supervise youth basketball competitions in Brazil, and in the present sample, players were engaged in official competitions in São Paulo and Santa Catarina, promoted by the *Federação Paulista de Basketball* and *Federação Catarinense de Basketball*, respectively. Clubs' programs run traditionally from February to July and August to November, completing nine months each season. Data were collected at each basketball club facility.

Players and their parents or legal guardians were informed of the nature of the study, the participation was voluntary, and they could withdraw from the study at any time. The study was approved by the Research Ethics Committee of the Federal University of Santa Catarina and by the Research Ethics Committee of the University of Campinas. Both athletes and their legal guardians provided written informed consent.

Measures

Anthropometric measures

We considered anthropometry measures taken by a single and experienced observer following standardized procedures, including stature and body mass. Intra-observer technical measurement errors were 0.25 cm for stature and 0.42 kg for body mass [26].

Chronological age and maturity status

Chronological age was considered to the nearest 0.1 years by subtracting a birth date from the testing date. Next, the sex-specific maturity offset equations were used to estimate age at peak height velocity (PHV) based on the age and stature prediction model [27]. The prediction model estimates the distance from PHV was calculated by subtracting the estimation from chronological age, i.e., the offset. With the offset estimation, we can derive each player's age at PHV. Often overlooked, the offset equations estimate timing (i.e., the age at which a given pubertal milestone is reached). However, the interest in interpreting young athletes' performance and development lies in tempo information, i.e., the rate of within-person progression through maturation stages [28]. To interpret variation in maturity status between individuals, we compared the estimates of timing obtained with the sex-specific offset equations against the population references based on meta-analysis estimations [14]. Hence, we compared the players' estimated age at PHV against a sex-specific reference age at PHV

derived from a meta-analysis of longitudinal growth studies [16]. Details of our procedure are available elsewhere [14]. Then we classified the young basketball players as follows: early maturers (n = 90), when estimated age at PHV was lower than the reference age at PHV by more than six months; average maturers (n = 52) when players' estimated age at PHV was within plus/minus six months of the reference age at PHV; late maturers (n = 5), when estimated age at PHV was higher than the reference age at PHV by more than six months.

Nevertheless, the limitations of the maturity offset protocol are assumed in our analysis [19], particularly at the extremes of the observed age range where bias is likely to be significant [29]. Therefore, we considered the maturity status of players from the under-13 for female players and under 13 and under-15 age groups for male players. Female under-15 and female and male under-17 players were categorized as not classified (n = 35). We assume our interpretations about the influence of maturity status on players across the ages that the offset protocol is less limited, i.e., the ages around the PHV [29].

Onset of specialization in basketball

The age of specialization in basketball was considered as the self-reported age when athletes started formal year-round participation in a single "signature" sport (basketball), including training and competition in basketball, under the supervision of a coach within a youth basketball program registered in the state basketball federation, and with no participation in practice and competition in other organized sport [14]. Hence, we follow a conceptual approach to specialization as year-round participation in a single "signature" sport, with limited participation in potential sport alternatives, with a deliberate focus on training and development in the pursuit of elite status [10, 13-15]. We defined the onset of specialization in basketball considering two biological maturation milestones, the age of initiation of the pubertal growth spurt and the age at PHV [14]. Based on available longitudinal data from growth studies in the general population [16], we estimated the sex-specific reference age of the biological milestones using a meta-analysis fitted with multilevel models. The reference age of initiation of the pubertal growth spurt and age at PHV was 9.4 [95% Credible Interval (CI) 9.0 to 9.8] years and 11.1 (95% CI 10.8 to 11.5) years for females and males, respectively. The reference age at PHV was 11.9 (95% CI 11.8 to 12.0) years and 13.9 (95% CI 13.8 to 14.0) years for females and males, respectively. Hence, the onset of specialization in basketball for the young basketball players was classified as follows: pre-puberty specialization (i.e., early specialization), when players start their specialization in basketball before the reference age of onset of pubertal growth (n = 84); mid-puberty, when players started basketball specialization between the references for the onset of pubertal growth and the age of PHV, i.e., during pubertal growth (n = 60); late-puberty, when the start of specialization in basketball occurred after the reference age at pubertal growth (n = 13). For the cases where it was impossible to retain the onset of specialization, we classified players as unknown (n = 25).

Note that this study did not consider deliberate play [3] and informal participation in other sports previous or after the specialization onset age in basketball. Therefore, similarly to our previous observations with cross-sectional data [14], we assume the limits of our data to

describe the continuum of sport participation of the sample, and caution is advised interpreting the data.

Physical fitness assessment
To describe players' basketball-specific physical fitness levels, we used the vertical jump with the countermovement jump [30], a short-term maximal running protocol with changes of direction, the line drill test [31], and intermittent endurance test, the yo-yo intermittent recovery level 1 test (yo-yo IR1) [32]. Details about the physical fitness assessments and reliability estimates in the present research project are available elsewhere [19, 26, 31]. The height of the best countermovement jump was retained to the nearest centimeter. Each time of the performance in the line drill test was recorded in seconds. The covered distance in the yo-yo IR1 was measured in meters. Based on the sum of the z-scores of each physiological measure, we estimated a score of overall physical fitness, i.e., physical fitness score (lower-limb explosive strength, agility and anaerobic power, and intermittent endurance). Given that lower times indicate better performance, the z-scores were reversed for the line drill test performance.

Statistical models

The repeated observations for each player across a season and, and multiple seasons, present an example of a complex hierarchical structure. To cope with a complex data structure, with imbalanced sample size and heterogeneity among and between players, we used a multilevel modeling approach in a fully Bayesian framework. Readers unfamiliar with Bayesian methods may be surprised that we do not report significance tests in our results. In its place, we will use a direct probabilistic interpretation of the models´ parameters to simulate predictions and assess the quality of model fit to data [33].

We used two model structures to examine changes within a competitive season, and developmental changes during adolescence.

Modeling changes within a competitive season
We fitted varying intercept, varying slope models to the repeated measures data, allowing for the possibility of varying intercepts (i.e., pre-season values) and slope (changes in players' outcomes across mid- and end-season) by players. In addition, we included sex as a population-level (also referred to as fixed effect) due to the difficulty of estimating the between-group variation when the number of groups is small [34]. Furthermore, we incorporate both within- and between-group variation in the model on the players' physical fitness changes across the competitive season. To capture variation in physiological responses by sex, we included an interaction term between sex and changes in players' outcomes across mid- and end-season. Also, to capture differences in physical fitness by sex, we allow players by sex to vary by the onset of specialization and age group maturity status. The group-level effect terms (also called random effects) and data-level terms (also called level-1 residuals) were drawn from normal distributions with variances to be estimated from the data. Note that some of these

variables include "Unknown" or "Not classified" values and keep these values as separate levels in the model. We partially pool within each group to allow the model to pick up trends in cases where there is not enough data or missing information to project the estimates onto the imbalanced repeated measures data.

When modeling the yo-yo IR1 and the overall physical fitness score responses, we included body mass (standardized) as a population-level effect to partition the influence of size on physical fitness outcomes, particularly long-term intermittent maximal performance [35]. However, there was no need to include body dimensions for the short-term maximal outputs, as the influence of size on performance was neglectable.

Modeling developmental changes

We fitted a basic three-level polynomial growth model curve [36] to model physical fitness indicators against chronological age. The model describes each player's successive measurements over time defining the player's change at each measurement point and its variation (level-1), differences in trajectories between players, and its variation (level-2), and differences in trajectories between players grouped by specialization onset, and its variation (level-3). To describe potential non-linear developmental changes during adolescence years we considered time (i.e., chronological age) coefficients up to the quadratic terms. We allowed for developmental trajectories to vary between players (level-2) and between players grouped by specialization onset.

Prior distributions

For interpretative convenience and to speed up computation, we standardized the outcomes by subtracting the mean and dividing by two standard deviations [34]. Given that young players' physical fitness outcomes tends to be heterogeneous and the available imbalanced repeated measures data, we were intentionally conservative on our interpretations. Hence, we used weakly informative priors to regularize our estimates. We used multivariate normal priors (0,5) for the population-level parameter (i.e., intercept and slopes) and exponential (1) priors for the group-level parameters. For the data-level residuals, we used the default prior, Student-t (3, 0, 2.5) [37].

Statistical software, code repository, and reproducibility

The length of the chains and warm-up was sufficient to achieve convergence and obtain a reasonable, effective sample size. We run four chains for 2,000 iterations with a warm-up length of 1,000 iterations for each model. The models were inspected and validated using posterior predictive checks [38]. The Bayesian multilevel models were fitted using R statistical language [39], with the "brms" package [37], which call Stan [40]. To extract the posterior samples and visualize the results, we used the "tidybayes" [41] and "ggplot2" [42] packages.

Results

Characteristics of the sample at pre-season, as reference for description, are summarized in Table 1. Under-13 and under-15 players were mostly classified as early or average maturers with an approximately 2 to 1 distribution of cases, respectively. The distribution of players by the onset of specialization in youth basketball within age groups is summarized in Table 2.

Table 1. Descriptive statistics of the sample at pre-season by age group and sex

	Under-13		Under-15		Under-17	
	Female	Male	Female	Male	Female	Male
Chronological age, years	12.5 (0.5)	12.6 (0.3)	14.2 (0.6)	14.2 (0.6)	16.0 (0.6)	15.9 (0.5)
Maturity offset, years	0.92 (0.67)	-0.44 (0.57)	b	1.04 (0.83)	b	b
Estimated age at PHV[a], years	11.6 (0.5)	13.1 (0.5)	b	13.1 (0.5)	b	b
Stature, cm	163.3 (9.5)	165.4 (11.0)	164.3 (5.6)	176.6 (11.0)	167.7 (3.9)	186.5 (7.5)
Body mass, kg	56.9 (13.6)	56.8 (16.1)	58.0 (8.5)	65.3 (13.3)	59.2 (8.4)	80.3 (11.0)
Countermovement jump, cm	24.3 (3.9)	31.7 (6.7)	25.0 (3.9)	35.6 (5.8)	25.7 (4.1)	38.9 (6.0)
Line Drill test, s	37.36 (1.88)	34.71 (3.37)	35.67 (1.93)	33.57 (3.70)	36.29 (1.82)	31.70 (3.09)
Yo-yo recovery test – level I, m	372.7 (82.2)	516.4 (305.6)	516.2 (175.7)	899.2 (382.8)	528.0 (171.6)	1203.3 (348.0)
Performance score, z-score sum	-1.41 (0.59)	-0.25 (1.47)	-0.92 (0.63)	0.65 (1.11)	-0.91 (0.69)	1.74 (0.96)

[a] *PHV: peak height velocity;* [b] *female under 15 and both female and male under 17 players were not classified by maturity status due to the lack of validity of the offset estimations*

Our models accounted for variation in the outcomes changes across a competitive season associated with age group, maturity status, and the onset of specialization. Hence, the effects of target groups can be interpreted as accounting for the other group effects. In the present study, our main focus was the contrasts by the onset of specialization. Predictions and uncertainty (68% credible intervals, i.e., approximately a standard deviation) of countermovement jump (Figure 1), Line drill test (Figure 2), yo-yo IR1 (Figure 3), and overall fitness score (Figure 4) changes across a competitive season are plotted, contrasting the onset of specialization within sex. We observed no substantial variation by the onset of specialization for both female and male players in the basketball-specific physical fitness changes across a competitive season. However, the trend of changes across a competitive season varied by sex. Female players showed slight improvements for countermovement jump, yo-yo IR1, and overall performance score. In contrast, male players maintained their physical fitness levels constant

across the competitive season. Overall, older players presented higher values for the indicators of physical fitness across the competitive season. There was no substantial variation in the physical fitness outcomes by maturity status in the responses across the competitive season. Supplementary plots of predictions of changes in the physical fitness outcomes across a competitive season by age group and maturity status within sex are available at https://osf.io/2gfw5/.

Table 2. Distribution of players by the onset of specialization within an age group and sex in the sample of young Brazilian players

|	Under-13		Under-15		Under-17		Total
	Female	Male	Female	Male	Female	Male	
Pre-puberty specialization	5	34	3	34	2	5	84
Mid-puberty specialization	12	21	9	15	1	3	60
Late-puberty specialization	5	Not possible	3	2	1	2	13
Unknown in the sample	0	7	0	12	0	6	25
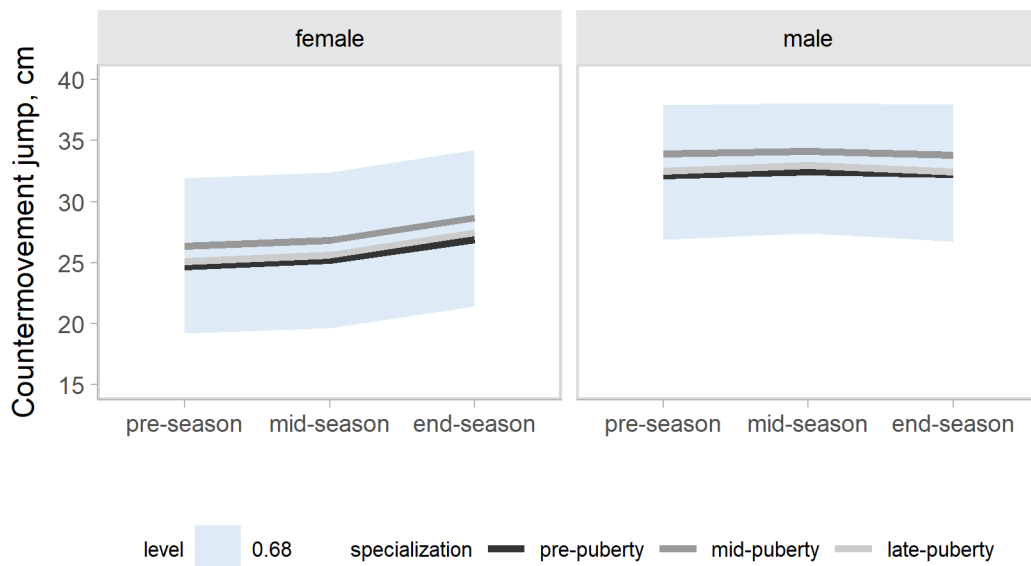
Figure 1. Changes in countermovement jump performance for young females and male basketball players within a basketball season by the onset of specialization. The shaded area represents the 68% credible interval, similar to a standard deviation.
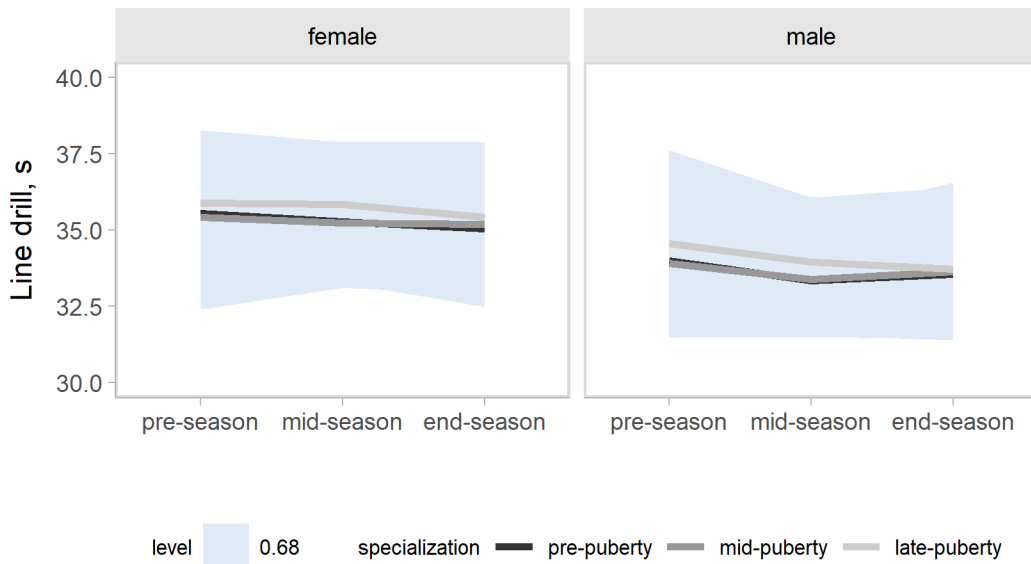
Figure 2. Changes in line-drill performance for young females and male basketball players within a basketball season by the onset of specialization. The shaded area represents the 68% credible interval, similar to a standard deviation.
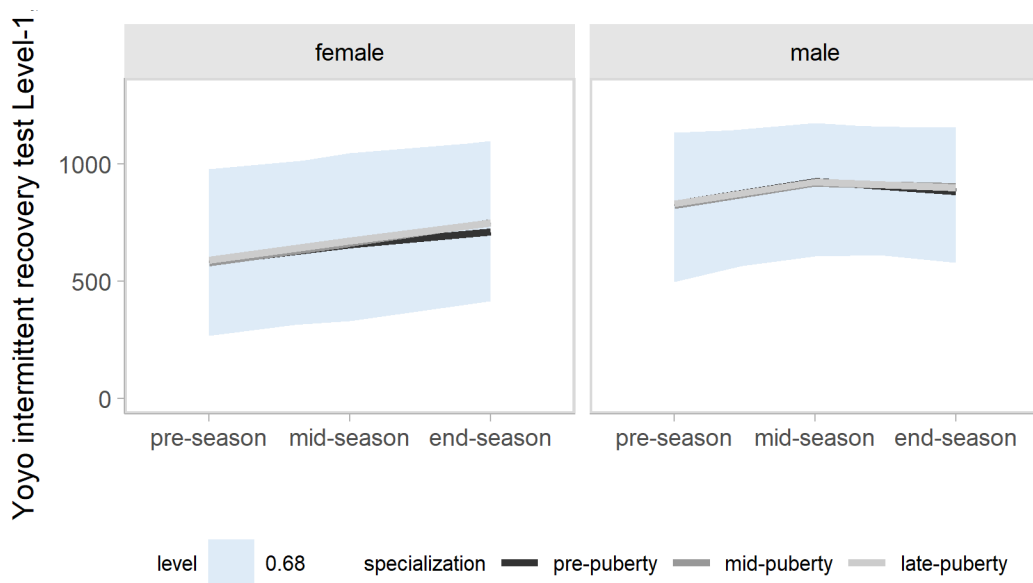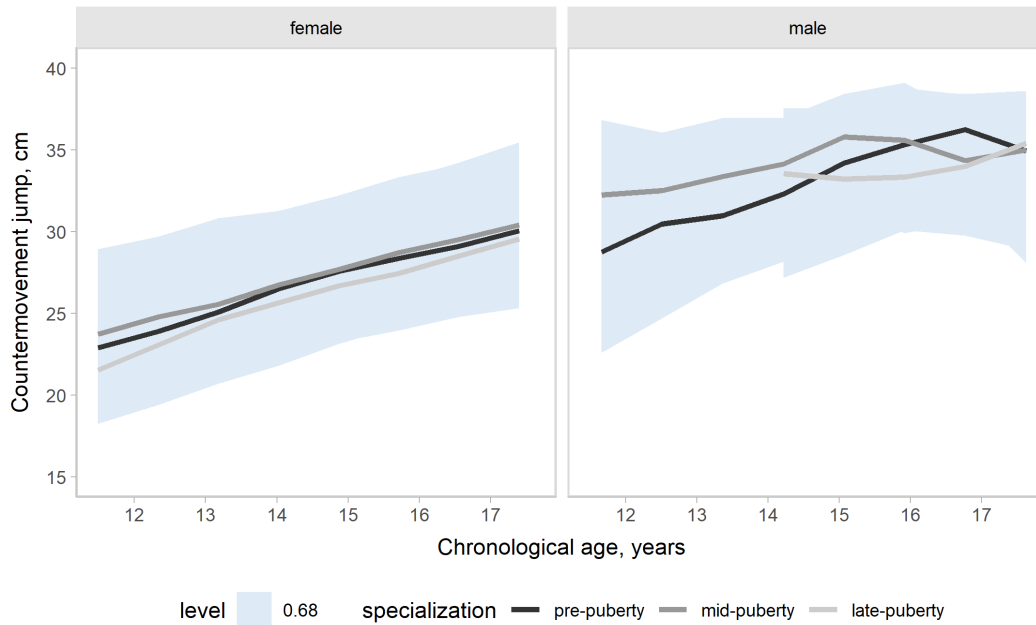

Figure 3. Changes in Yo-yo intermittent recovery test level 1 performance for young females and male basketball players within a basketball season by the onset of specialization. The shaded area represents the 68% credible interval, similar to a standard deviation.
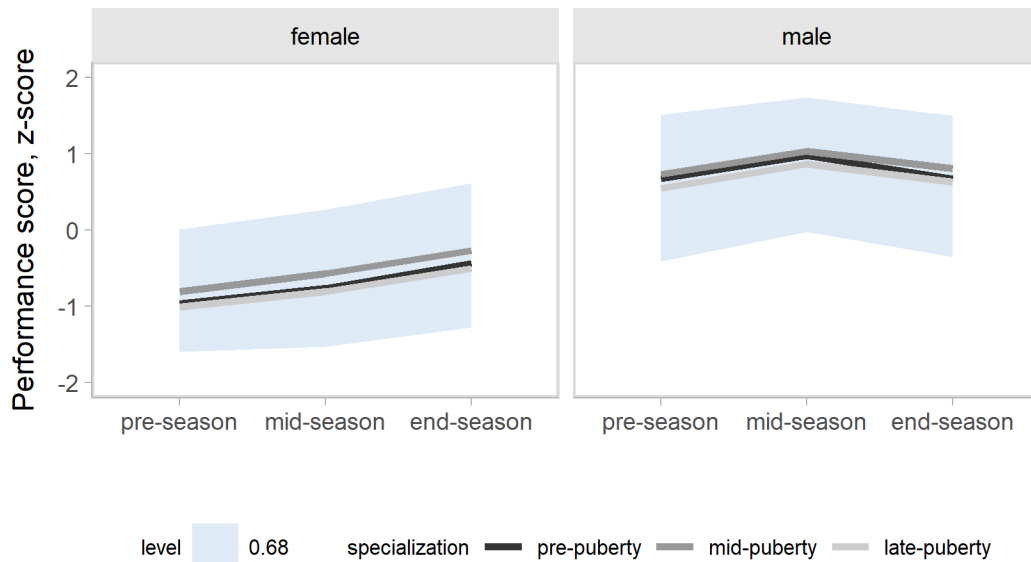
Figure 4. Changes in overall basketball-specific physiological performance index for young females and male basketball players within a basketball season by the onset of specialization. The shaded area represents the 68% credible interval, similar to a standard deviation.

Our three-level growth models accounted for variation in the outcomes changes between 11-17 years, accounting for the potential influence of the specialization onset. Predictions and uncertainty (68% credible intervals) of countermovement jump (Figure 5), Line drill test (Figure 6), yo-yo IR1 (Figure 7), and overall fitness score (Figure 8) developmental changes are plotted, contrasting the onset of specialization within sex. Notably, there was no substantial variation by the onset of specialization for both female and male players in the basketball-specific physical fitness developmental changes. We observed differences in magnitude and pattern of developmental changes in physical fitness between female and male players when aligned by chronological age. The plots contrasting developmental changes by sex for countermovement jump (Supplementary figure 9), Line drill test (Supplementary figure 10), yo-yo IR1 (Supplementary figure 11), and overall fitness score (Supplementary figure 12) are available at https://osf.io/2gfw5/.

Figure 5. Developmental changes in countermovement jump performance for young females and male basketball players by specialization onset. The shaded area represents the 68% credible interval, similar to a standard deviation.
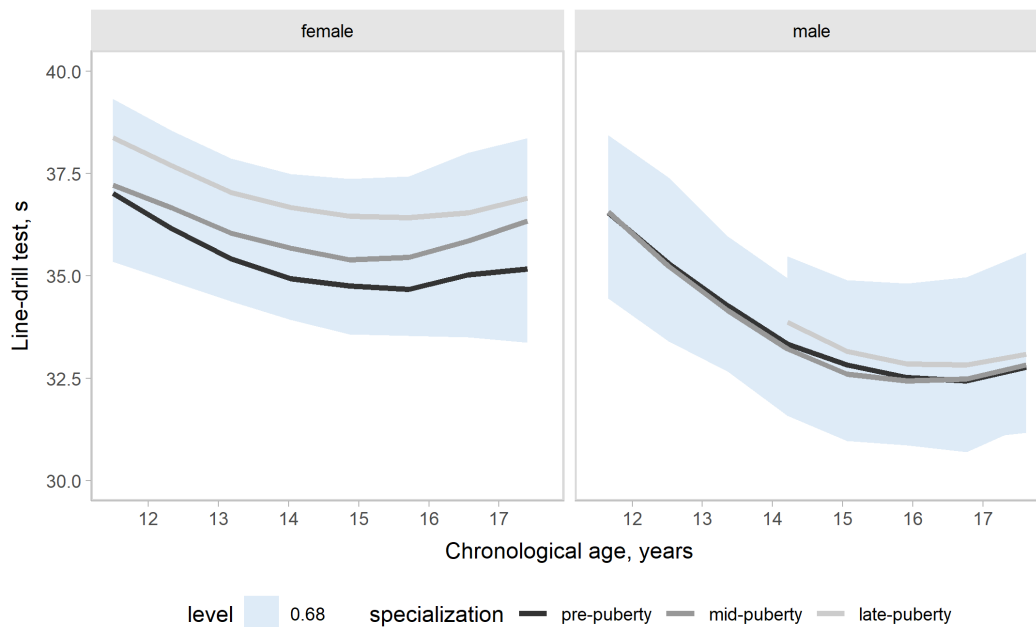
Figure 6. Developmental Changes in line-drill performance for young females and male basketball players by specialization onset. The shaded area represents the 68% credible interval, similar to a standard deviation.
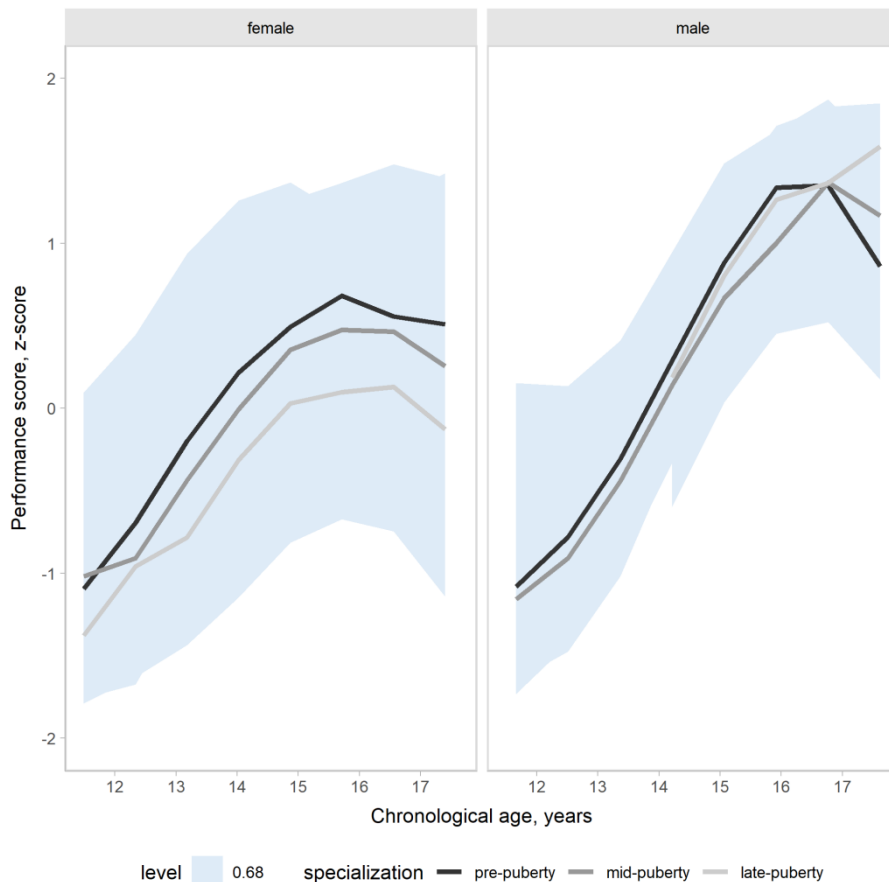
11
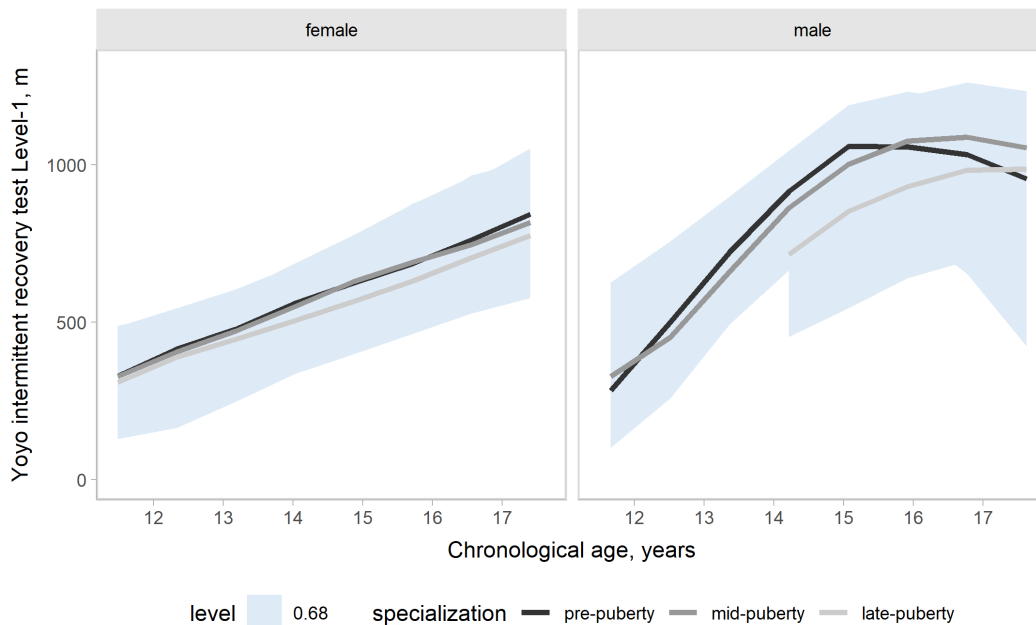
Figure 7. Developmental changes in Yo-yo intermittent recovery test level 1 performance for young females and male basketball players by specialization onset. The shaded area represents the 68% credible interval, similar to a standard deviation.

Discussion

The most interesting observation in this study is that players who specialize early in basketball (i.e., pre-puberty specialization) do not appear to have an advantage in basketball-specific physical fitness levels development. Conditional on our data, early specialization in youth basketball does not provide an advantage in developing physical across a season. Improvements in basketball-specific performance across a competitive season were apparent only for female players, while male players appear to maintain the physical fitness levels across a competitive season, adjusting for age group and estimated maturity status. Physical fitness developmental advantages were also not observed for players with early specialization. Therefore, young basketball players who specialize before pubertal growth (early) do not appear to have better physical fitness and develop faster than those who specialize during or after the pubertal growth period.

The growth characteristics of the present sample of Brazilian female and male adolescent basketball players were consistent with other reports with heterogeneous samples of young athletes [43] and young basketball players [19, 22, 23, 44, 45]. Overall, the somatic indicator suggests that the sample of female and male players across the age span of pubertal growth had an advanced maturity status. Nevertheless, caution is warranted when interpreting

and generalizing the maturity status of young athletes based on somatic maturity indicators as the prediction equations have limited validity [19, 29].

Figure 8. Developmental changes in overall basketball-specific physiological performance index for young females and male basketball players by specialization onset. The shaded area represents the 68% credible interval, similar to a standard deviation.

Sport specialization, in particular, early specialization, is a key issue in organized youth sports. Despite the interest and concerns surrounding children's early exposure to intense sports competition, little scientific information is available to support or refute these risks [7, 46-48]. It has been argued that there is a lack of evidence that specialization before puberty is necessary to achieve elite status, and that specialization before puberty is more likely to be detrimental [49]. Nevertheless, these interpretations are mainly based on inconsistent evidence with a potential sample bias [50]. On the other hand, early specialization appears to have become the common modus operandi in competitive youth sports [1, 7, 13]. The assumption that early sport specialization provides a physiological advantage for future athletic success [6] may result from interpreting the deliberate practice theory [2] applied to youth sports.

Conditional to our data and models, early specialization in youth basketball (i.e., pre-puberty specialization) does not provide an advantage in the development of basketball-specific physical fitness, or improved better responses within a season.

Another issue that biases the discussion about sports specialization is the inconsistent definition of early specialization [9-11]. In some cases, the operational definition of early specialization is based on the stages of developmental models, establishing the age of 12 years as a reference. In other reports, it is unclear how early (or late) specialization is operationalized [11]. Therefore, to understand the mechanisms behind early (and late) specialization and why it is potentially harmful or beneficial, first it must be established what early specialization is and the best methods to assess it [9].

Youth sports participation and specialization can be conceptualized as a continuum. We propose that specialization can be defined and interpreted relative to biological maturation milestones describing the pubertal growth period, i.e., the age of initiation of the pubertal growth spurt and the age at peak height velocity (PHV). We used a meta-analysis to establish the references conditional on general population growth patterns 14. We defined, in general, specialization as year-round participation in a single "signature" sport, with limited participation in potential sport alternatives, with a deliberate focus on training and development in the pursuit of elite status [10, 13, 14].

We believe we captured the main characteristics of the process, allowing for variation between sports specificities and contexts. Hence, players who attain the conditions defined as specialization before about nine years and 11 years for girls and boys, respectively, are considered as experiencing early specialization. On the other hand, late specialization may be interpreted as those players who attain the conditions defined as specialization after the age at PHV, about 12 years for girls and 14 years for boys.

The study of the development of physical fitness levels of basketball players during a basketball-competitive season is limited, and even more in young players [24, 25]. The interpretation of the data is limited by the small number of studies, each with small sample sizes and measurement errors associated with the performed tests [51-54]. As a result, the changes (decreases or improvements across a season by competitive level or starters vs. nonstarters) are trivial or inconclusive. Nevertheless, the observations with young basketball players from the Australian national- and state-level developmental programs showed a trend of improvement in physical fitness assessments across a season [25], particularly in the Line drill test [24]. Also, the physical fitness changes across a season varied by sex and competitive level among the young Australian basketball players [24, 25]. The young male players in the present sample maintained their physical fitness levels across a competitive season. In contrast, the female players showed a slight improvement in their fitness within a season. Nevertheless, given the variability in our predictions, a conservative interpretation and generalization should be taken.

Longitudinal data considering physical fitness development in youth basketball is scarce [20, 55, 56]. Conditional on the data, physical fitness outcomes improved, on average, with age from 11 to 17, for both female and male players. On average, young male players showed higher values in the fitness indicators than young female players. It was apparent that players

showed increased rates of fitness development overlapping with the period pubertal growth. For female players, a leveling-off on fitness development was apparent earlier than male players, particularly visible in the Line drill test. Sex-related differences in the timing and magnitude of the physical fitness outcomes development are likely associated with sexual dimorphism during pubertal growth that underlies physiological functions [4, 57]. Sex-related differences in fitness became apparent as girls, on average, attain biological milestones in puberty earlier than boys, albeit the large between-individual variation in the timing and tempo of biological maturation [4].

Our study provided valuable data regarding the interpretation of seasonal variations and developmental changes in basketball-specific physical fitness variables in adolescent basketball players. Nevertheless, the available unbalanced sample size, context specificities, and maturity indicator limitations warrant caution when compared with other adolescent basketball players. However, the multilevel modeling in a fully Bayesian framework allows dealing with non-representative and imbalanced samples, with hierarchical sources of variation and cross-classified nesting [34]. Bayesian methods comprise samples from the joint posterior density of the parameters [33]. It allows for direct probabilistic interpretation of credible (also referred to as compatibility or uncertainty intervals) intervals and posterior probabilities [58]. Bayesian methods should be of interest for those concerned in estimations of very small effects, typical of within-athletes changes in response to training, measured with noisy measurements, as is often the case with physical fitness outcomes.

In summary, based on our data and models, early specialization before the onset of pubertal growth does not provide an advantage in basketball-specific physical fitness development across a season in youth basketball. Hence, the argument/myth that early sport specialization provides a fitness advantage for future athletic success does not hold. Overall, young athletes, coaches, and interested stakeholders should be conservative in their expectations of improvements of physical fitness across a season in young basketball players. Furthermore, we provide an operational framework to interpret specialization related to biological maturation milestones.

Contributions

Contributed to conception and design: HMC, CEG, RRP
Contributed to acquisition of data: ALAS, ABL, CGM, LG, TJL
Contributed to analysis and interpretation of data: HMC, CEG, ALAS
Drafted and/or revised the article: HMC, CEG, ALAS
Approved the submitted version for publication: ALAS, ABL, CGM, LG, TJL, RRP,CEG, HMC

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Data and Supplementary Material Accessibility

The data, codes, and supplementary material are available at https://osf.io/2gfw5/.

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