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Research article

Testing The Effects of Player Matching in Basketball Matches and Small-Sided Game Training Scenarios Based on The Relative Age Effect: A 6-Month Study on Physical Performance and Skill Adaptations

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Abstract
Identifying strategies to mitigate the impact of the Relative Age Effect (RAE) on the development of youth basketball players is crucial. This study aimed to compare two methods of player grouping during competitive small-sided games and match scenarios in training sessions, focusing on their impact on physical performance and technical skill development: mixed birthdate quartiles (CON) versus structured grouping based on birthdate quartiles (BG) over a 6-month period. A randomized controlled trial was conducted with forty-one youth basketball players (age: 12.9 ± 0.7 years) at a trained/developmental level. Throughout the study, participants in the BG group (n = 20) were assigned to small-sided games or match competition scenarios based on their birthdate quartiles, while those in the CON group (n = 21) were grouped with players from mixed quartiles. Players were evaluated at baseline and after the 6-month period for physical performance using countermovement jump (CMJ), change-of-direction (COD), and aerobic capacity (YYIRT). Additionally, they were assessed for technical skills in shooting, passing, and dribbling tests. Comparisons were made based on both birthdate quartiles (quartiles q1-2 relatively older, and q3-4 relatively younger players) and group. After 6 months, the CONq3q4 covered a shorter YYIRT distance than the CONq1q2 group ($p = 0.040$), achieved a lower CMJ height than both the CONq1q2 ($p = 0.024$) and BGq1q2 groups ($p = 0.019$), and had a greater COD deficit than the CONq1q2 group ($p = 0.046$). Additionally, the CONq3q4 group had longer dribbling times than the CONq1q2 ($p = 0.002$), BGq1q2 ($p = 0.004$), and BGq3q4 ($p = 0.009$) groups. In skill assessments, the CONq3q4 group scored lower in passing than both the CONq1q2 ($p = 0.015$) and BGq1q2 groups ($p = 0.025$), and scored lower in shooting compared to the CONq1q2 ($p = 0.019$), BGq1q2 ($p = 0.003$), and BGq3q4 ($p = 0.003$) groups. Grouping youth basketball players based on birthdate quartiles during training can mitigate the relative age effect, promoting more equitable physical and technical development by reducing age-related biases. However, these conclusions are limited by the study's duration and require further research over the long term.

Key words: Youth sports, sports training, athletic performance, technical, skill.

Introduction

Research consistently demonstrates the presence of Relative Age Effects (RAEs) in youth basketball, with players born earlier in the selection year being overrepresented (Ibáñez et al., 2018; Gonçalves and Carvalho, 2021; Bilgiç et al., 2025). RAEs can influence player selection, with early-born athletes up to 8.4 times more likely to be included in squads (Bilgiç et al., 2025). These effects are particularly pronounced in younger age groups closer to peak of maturation (12 - 14 years old) and lower-ranked teams (Rubajczyk et al., 2017; Ibáñez et al., 2018). RAEs can impact physical attributes like height and body mass (Rubajczyk et al., 2017) and performance indicators, especially for certain playing positions (Ibáñez et al., 2018). For instance, a previous study found that relative age effect is evident in youth basketball, with older players performing better and playing more minutes, especially in younger age groups (Arrieta et al., 2016). However, some studies suggest that RAE advantages may diminish over time (Gonçalves and Carvalho, 2021).

While RAEs generally favor older players within age groups, studies have found no significant differences in technical skills between relatively older and younger athletes (Schorer et al., 2009; 2015). Aligned with this, technical skills appear to be more influenced by years of training rather than maturation (Guimarães et al., 2019). However, maturation status does influence physical characteristics and some functional capabilities, with early-maturing players showing advantages in body mass, height, and certain fitness parameters (Gouvea et al., 2016; Toselli et al., 2022). It is important to emphasize that RAE is a different concept from maturation. While RAE refers to the advantage that older players within an age group may have due to being born earlier in the selection year, the effects of RAE can indirectly interact with biological maturation. However, this relationship is not necessarily linear, as RAE pertains more to the relative age within a cohort (Peña-González et al., 2018), while maturation involves individual biological development, which can vary significantly across players.

Although overall technical skill levels may not be highly sensitive to maturation and RAEs, competing against taller, heavier players with superior physical performance at a given moment can affect an athlete's ability to remain competitive in specific drills. For example, a previous study on small-sided games found that 4 vs. 4 ball-possession drills provide different performance-related stimuli depending on the players' age category and the playing surface area (Nunes et al., 2021). Moreover, another study in small-sided games revealed that body size, skeletal age, and motor performance influenced technical skills in youth players (da Costa et al., 2023).

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If the level of participation in training scenarios varies among youth players - particularly at ages where RAEs have a greater impact, and maturation plays a significant role - this trend may also be observed in matches. A previous study revealed that early-maturing players often dominate national championships, scoring more points and providing more assists (Arede et al., 2021). This finding is consistent with another study in basketball, which indicates that maturity and relative age are linked to enhanced performance in elite adolescent players (Torres-Unda et al., 2016). To counteract the potential effects of RAEs on performance - which can ultimately influence talent selection due to momentary decisions made by coaches during the critical period of adolescence (Kelly et al., 2021) - various approaches have been proposed. One such approach is balancing competition by grouping athletes based on birth, aiming to reduce discrepancies caused by RAEs (Cobley et al., 2009). This can be used by considering the player quota and the team's regulation average, or even by extending this approach to the training context (Webdale et al., 2020).

Although the topics mentioned above are highly relevant, research in this area remains limited, with most studies focusing primarily on describing the existence of RAEs rather than exploring their practical implications (de la Rubia Riaza et al., 2020). Specifically, little attention has been given to how RAEs influence the structure of training processes and competition within training environments, such as during small-sided games and regular competitive matches. In these scenarios, players are able to compete in dynamic situations. One potentially valuable approach is balancing team composition based on birthdate quartiles: Quartile 1 (born between January and March), Quartile 2 (born between April and June), Quartile 3 (born between July and September), and Quartile 4 (born between October and December). This strategy could help determine whether such grouping positively influences players' physical and technical development over time while also fostering a more equitable and competitive team environment. Understanding whether birthdate-based balancing is more effective than the traditional mixed approach could serve as a foundation for new methodological advancements in youth basketball training. Such insights could refine future training strategies and enhance the individualization of player development. Moreover, future research may reveal whether this approach can help mitigate the risk of dropout caused by unequal competition due to RAE (Delorme et al., 2011).

Given the significance of this issue, the purpose of this study was to compare two methods of grouping players during competitive small-sided games and match scenarios in training sessions - mixed birthdate quartiles (CON) versus structured grouping by birthdate quartiles (BG) - over a 6-month period. The study aimed to assess the impact of these methods on the development of physical performance (specifically countermovement jump, change of direction, and aerobic performance) and technical skills (specifically shooting, passing, and dribbling) in male youth basketball players. We hypothesize that structured grouping can balance the playing challenges and contribute to the homogenization of physical fitness and technical skill development in youth basketball players.

Methods

Experimental approach

Over a 6-month period, four regional-level youth basketball teams participated in a training program where both the CON and BG conditions were implemented. In the BG condition, players participated in all small-sided games or match scenarios, with teams always matched based on the players' birthdate quartiles. In contrast, in the CON condition, players were randomly assigned to teams with a mix of players from different birthdate quartiles, both within their own team and in opposing teams. The study took place during the first half of the basketball season, beginning 2 weeks after the start of the preseason. During this period, 49 training sessions were implemented, with the matching condition serving as a key constraint for the training structure. Players were evaluated for their physical and technical performance at baseline and after the 6-month period.

Participants

This study involved male youth basketball players, ranging in age from 12 to 14 years, recruited from local basketball clubs. Eligibility criteria included participants in competitive basketball with over two years of experience, and regularly attending training sessions and games. Players were eligible if they possessed a minimum of 24 months of basketball experience and had not sustained an injury lasting longer than three weeks during the observation period. Exclusion criteria encompassed injuries that would impede participation in testing procedures, as well as participants with injuries exceeding three weeks. Players withdrawing before the completion of follow-up assessments were excluded from the final analysis.

A total of 48 players underwent initial screening, and following the application of inclusion and exclusion criteria, 41 players were enrolled. Participants were categorized into two groups: a group of players assigned to teams with a mix of players from different birthdate quartiles, both within their own team and in opposing teams (CON; n = 21), and one group of players participated in all small-sided games or match scenarios, with teams always matched based on the players' birthdate quartiles (BG; n = 20). Players engaged in training sessions three times per week, along with weekend competitive matches. Each training session typically included a warm-up, brief conditioning exercises focusing on either aerobic fitness or agility, analytical drills aimed at refining technical skills, and some using small-sided games and others using match scenarios. On average, the sessions lasted 105.6 ± 10.3 minutes.

Ethical approval was granted by the Chengdu Sport University ethics committee (approval code [2024#102], date [02/09/2024]), ensuring compliance with institutional and regulatory ethical guidelines. Due to the participants' minor status, informed consent was obtained from their legal guardians, and assent was provided by the participants themselves. The research adhered to the ethical principles outlined in the Declaration of Helsinki, emphasizing respect for human dignity, minimizing risks, and upholding scientific integrity.

Intervention

Among the four teams involved in this study, two were randomly assigned to match players in training scenarios based on mixed birthdate quartiles (CON), while the other two teams used birthdate-quartile matching (BG). The coaches, guided by their existing training plans, managed the daily implementation of this matching process, with researchers ensuring accurate player allocation during game simulations. While the coaches designed and conducted the training, researchers specifically oversaw the matching of players during game scenarios. This strategy, using two teams per matching condition, aimed to mitigate contextual training bias and ensure that training planning did not influence the outcomes. The matching process was conducted on a session-by-session basis, under the supervision of the research team.

For example, in a 3v3 small-sided game with 12 players in the team (2 born in January, 3 in February, 1 in March, 2 in June, 1 in August, 2 in September, and 1 in December), players in the BG condition were grouped by birthdate proximity. Thus, the initial 3v3 would consist of the players born in January (2), February (3), and March (1). After allocating players to this first game, subsequent 3v3 groups were formed using the same birthdate proximity principle. Conversely, the CON condition used a mixed birthdate distribution, such as January (1), March (1), June (1), August (1), September (1), and December (1).

To streamline the process, coaches provided training plans to researchers the day before each training session. Researchers then assigned players to either the CON or BG condition, specifying the participants for each small-sided game or match scenario. Importantly, teams and player assignments were fixed; teams and players assigned to CON or BG at baseline remained in that condition throughout the 6-month study period. All training sessions took place in an indoor basketball court within a controlled environment, with temperatures ranging from 19 to 22ºC throughout the period.

Measurements and procedures

Performance assessments were conducted at baseline and 6 months post-baseline, during the initial weekly training session, following a 48-hour post-match recovery period. All evaluations were consistently scheduled for the afternoon (4:00 PM) and adhered to a standardized sequence. Participants began with a standardized warm-up, followed by the basketball shooting drill, with a two-minute rest period. Subsequently, the passing test was administered, followed by another two-minute rest, and then the dribbling test. Next, the countermovement jump (CMJ) and 5-0-5 change of direction (COD) tests were performed, with a two-minute rest period between them. Finally, aerobic capacity was assessed using the Yo-Yo Intermittent Recovery Test Level 1. This standardized protocol was maintained across both testing sessions to ensure data consistency and comparability.

Countermovement jump (CMJ)

Lower-body explosive power was assessed using the countermovement jump (CMJ) test, employing the MyJump 2 mobile application. This application was chosen due to its established reliability and validity in measuring jump height when compared to gold-standard force platforms (Stanton, Wintour and Kean, 2017). Participants, after receiving specific test instructions, completed a non-counted familiarization jump. Subsequently, they performed two maximal CMJ trials, with a 30-second rest interval between each. The average jump height from these two trials, expressed in centimeters (cm), was used as the primary outcome measure for subsequent data analysis.

Change-of-direction (COD)

Change of direction (COD) ability was assessed using the 5-0-5 COD test. Participants performed the test, which involved a 10-meter sprint followed by a 5-meter approach to a turning line, a 180-degree change of direction, and a 5-meter sprint back through the timing gates. Time was measured using Photo Finish mobile application placed at the start of the test, at the 5-meter start/finish line and at the 5-meter turning line. The reliability and validity of the Photo Finish mobile application have been previously established in comparison to photocells (Marco-Contreras et al., 2024). Participants performed two trials for both the right and left turns, and the fastest time for each direction was recorded. The COD deficit was then calculated by subtracting the 10-meter sprint time from the total 5-0-5 COD time (Nimphius et al., 2016). This deficit, expressed in seconds (s), represented the time lost during the change of direction and served as the primary outcome measure for subsequent data analysis.

Yo-Yo Intermittent Recovery Test – Level 1

Aerobic endurance and intermittent exercise capacity were assessed using the Yo-Yo Intermittent Recovery Test Level 1 (YYIR1). Participants performed repeated 2 x 20-meter shuttle runs, starting at a velocity of 10 km/h. The running speed progressively increased by 0.5 km/h at each subsequent level, dictated by audio beeps. Participants had a 10-second active recovery period between shuttles. The test continued until participants failed to maintain the required pace on two consecutive shuttles. The total distance covered before failure, measured in meters (m), was recorded as the primary outcome measure, reflecting the participant's capacity for high-intensity intermittent exercise.

Shooting test

Basketball shooting proficiency was evaluated using a modified 60-second shooting drill, previously utilized in youth basketball study (Coelho E. Silva et al., 2008). Participants began behind one of five markers (as described in the original study (Coelho E. Silva et al., 2008), each positioned approximately 4.54 meters from the basket. Upon initiating the drill, players were instructed to shoot, retrieve the ball, dribble to a different designated marker, and repeat the shooting sequence as quickly as possible within the 60-second time limit (Coelho E. Silva et al., 2008). To ensure comprehensive shooting skill assessment, players were required to attempt at least one shot from each marker. A maximum of four lay-up shots was permitted during the trial, but consecutive lay-ups were prohibited. A pilot study involving 10 players who were not part of the main study, in which each player repeated the test on two separate days, showed a mean intra-player coefficient of variation of 4.7%. Scoring was as follows: two points for each successful basket (including lay-ups) and one point for any unsuccessful shot that contacted the rim from above. The total points (n) accumulated within the 60-second period served as the primary shooting performance measure.

Passing test

Basketball passing accuracy and lateral movement were evaluated using a 30-second wall passing drill as previously presented in the original study (Coelho E Silva et al., 2008). Participants stood behind a 2.45-meter restraining line, facing a wall marked with six distinct 60x60cm target squares (A-F) (Coelho E Silva et al., 2008). The targets were positioned at alternating heights, with their bottom edges 1.5 meters (A, C, E) and 90 centimeters (B, D, F) from the ground (Coelho E Silva et al., 2008). Participants performed chest passes to the targets in a predetermined sequence while laterally moving and retrieving the ball, ensuring they remained behind the restraining line. A pilot study involving 10 players who were not part of the main study, in which each player repeated the test on two separate days, showed a mean intra-player coefficient of variation of 2.8%. Scoring was as follows: two points were awarded for passes that struck a target square or its boundary and one point for passes that hit the wall between the targets. The total points (n) accumulated within the 30-second period represented the participant's passing skill and accuracy.

Dribbling test

Dribbling agility was assessed using a timed obstacle course as presented in the original study (Coelho E. Silva et al., 2008), designed to evaluate ball-handling proficiency and maneuverability. Participants were required to navigate a six-cone dribbling circuit, arranged within a 5.8 x 3.6 meter rectangular area, as quickly as possible (Coelho E. Silva et al., 2008). The time to complete the course was measured using the Photo Finish mobile application (Marco-Contreras et al., 2024). Participants began with their non-dominant hand positioned on the non-dominant side of cone A. They then dribbled with their non-dominant hand to the non-dominant side of cone B, followed by dominant-hand dribbling to cones C and D. The course continued with non-dominant hand dribbling to cone E and concluded with dominant-hand dribbling to cone F. A pilot study involving 10 players who were not part of the main study, in which each player repeated the test on two separate days, showed a mean intra-player coefficient of variation of 4.2%. The total time (s) taken to complete the circuit served as the primary measure of dribbling agility.

Sample size, randomization and blinding

Sample size was determined using G*Power software (version 3.1.9.6.). A power analysis was conducted to ensure adequate statistical power to detect a meaningful effect. Based on an estimated medium effect size (Cohen's f = 0.25), an alpha level of 0.05, and a desired power of 0.80, the analysis indicated a minimum sample size of 34 participants would be required. To ensure unbiased allocation, participants were randomized to groups using sequentially numbered, opaque envelopes. Each envelope contained the assigned group, and participants were assigned based on the order in which they were recruited. To maintain objectivity during outcome assessment, blinding was implemented for the evaluation process. External evaluators, who were unaware of the participants' group assignments, conducted all assessments. This ensured that the evaluation was free from potential bias related to knowledge of group allocation.

Statistical procedures

To analyze the data, a mixed-ANOVA was conducted to examine the differences between two groups (CON birthdate quartiles 1 and 2; CON quartiles 3 and 4; BG birthdate quartiles 1 and 2; BG birthdate quartiles 3 and 4) at two time points (baseline and post-6 months). The mixed-ANOVA allowed for the evaluation of both within-subject (time) and between-subject (group) effects, as well as their interaction. Prior to conducting the analysis, the assumptions of normality, sphericity, and homogeneity of variances were assessed. Normality was evaluated using visual inspection of histograms and the Shapiro-Wilk test ($p > 0.05$). Sphericity was tested using Mauchly's test, and any violations were addressed with a Greenhouse-Geisser correction. Homogeneity of variance was assessed using Levene's test ($p > 0.05$). Effect sizes were calculated using partial eta squared (ηp^2). For partial eta squared, small, medium, and large effects are defined as $\eta p^2 = 0.01$, $\eta p^2 = 0.06$, and $\eta p^2 = 0.14$, respectively. Cohen's d was also used to interpret the practical significance of the results, with small, medium, and large effects typically corresponding to d values of 0.2, 0.5, and 0.8, respectively (Cohen, 1988). The statistical analysis was performed using SPSS (version 28, IBM, USA), with a significance level set at $p < 0.05$.

Results

The participants included in the study were 12.9±0.7 years old, 152.8 ± 8.9 cm in height, 45.8 ± 7.2 kg in weight, and had a body mass index (BMI) of 19.6 ± 2.2 kg/m², with a maturity offset of -1.06 ± 0.77 years. The CON group (n=21) had an average age of 12.8 ± 0.7 years, height of 152.0 ± 8.2 cm, weight of 44.9 ± 6.7 kg, BMI of 19.4 ± 2.4 kg/m², and a maturity offset of -1.05 ± 0.71 years, while the BG group (n=20) had an average age of 13.0 ± 0.6 years, height of 153.6 ± 9.7 cm, weight of 46.8 ± 7.7 kg, BMI of 19.7 ± 2.0 kg/m², and a maturity offset of -1.06 ± 0.85 years. Figure 1 illustrates the allocation and follow-up of the players.

Significant interactions between the assessment timing and the groups were observed for YYIRT ($p<0.001$; $\eta p^2 = 0.742$), CMJ ($p < 0.001$; $\eta p^2 = 0.393$), shooting ($p < 0.001$; $\eta p^2 = 0.610$), passing ($p < 0.001$; $\eta p^2 = 0.671$), and dribbling ($p < 0.001$; $\eta p^2 = 0.859$), but not for the COD deficit ($p = 0.118$; $\eta p^2 = 0.145$).

No significant differences were found between groups at baseline for the variables of COD deficit ($p = 0.941$; $\eta p^2 = 0.010$), YYIRT ($p = 0.999$; $\eta p^2 = 0.001$), CMJ ($p = 0.976$; $\eta p^2 = 0.006$), shooting ($p = 0.733$; $\eta p^2 = 0.034$), passing ($p = 0.877$; $\eta p^2 = 0.018$), and dribbling ($p = 0.994$;

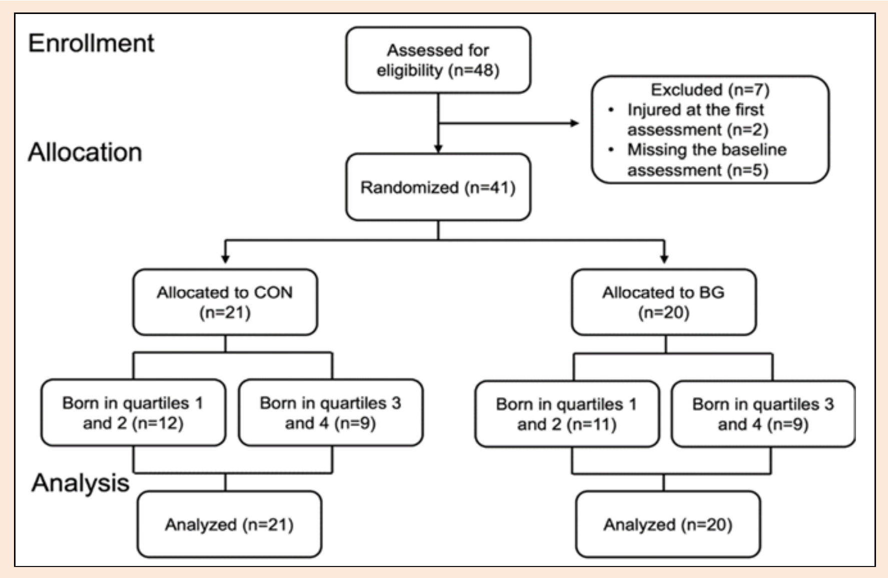

Figure 1. Flowchart showing player allocation and follow-up process.

ηp^2 = 0.002). However, significant differences were observed after 6 months for COD deficit (p = 0.029; ηp^2 = 0.214), YYIRT (p = 0.025; ηp^2 = 0.220), CMJ (p = 0.012; ηp^2 = 0.252), shooting (p = 0.001; ηp^2 = 0.344), passing (p = 0.011; ηp^2 = 0.259), and dribbling (p < 0.001; ηp^2 = 0.353). Table 1 presents the mean values and standard deviations for all outcomes across the assessment periods.

Figure 2 illustrates the YYIRT and CMJ values for each group across the assessment periods. After 6 months, the CONq3q4 group (Q3Q4: players born between July and December) covered a significantly shorter YYIRT distance compared to the CONq1q2 group (p = 0.040; Cohen's d = 1.124). Additionally, after 6 months, the CONq3q4 group achieved a significantly lower CMJ height compared to both the CONq1q2 group (q1q2: players born between January and June) (p = 0.024; Cohen's d = 1.515) and the BGq1q2 group (p = 0.019; Cohen's d = 1.238).

Figure 3 shows the COD deficit and dribbling values for each group across the assessment periods. After 6 months, the CONq3q4 group exhibited a significantly greater COD deficit compared to the CONq1q2 group (p = 0.046; Cohen's d = 1.222). Additionally, after 6 months, the CONq3q4 group had a significantly longer dribbling time compared to the CONq1q2 group (p = 0.002; Cohen's d = 2.000), the BGq1q2 group (p = 0.004; Cohen's d = 2.000), and the BGq3q4 group (p = 0.009; Cohen's d = 1.714).

Figure 4 presents the shooting and passing values for each group across the assessment periods. After 6 months, the CONq3q4 group scored significantly lower in passing compared to both the CONq1q2 group (p = 0.015; Cohen's d = 1.388) and the BGq1q2 group (p = 0.025; Cohen's d = 1.200). Additionally, after 6 months, the CONq3q4 group scored significantly lower in shooting compared to the CONq1q2 group (p = 0.019; Cohen's d = 1.459), the BGq1q2 group (p = 0.003; Cohen's d = 1.610), and the BGq3q4 group (p = 0.003; Cohen's d = 1.659).

Discussion

The current research revealed that when youth basketball players are not grouped based on their birthdates during training - specifically in small-sided and match-related games - those born in the third and fourth quartiles tend to fall behind in both physical and technical development. Specifically, after six months, players born in quartiles 3 and 4 showed significantly worse performance in COD deficit, YYIRT, CMJ, shooting, passing, and dribbling compared to their peers in quartiles 1 and 2 when training in mixed birthdate groups. However, when players were grouped according to birthdate, development was more balanced between those born earlier and later in the year, thereby reducing the disparity caused by RAEs. This study is novel in showing, with longitudinal data, that birthdate-based grouping during ecologically training scenarios may actively counteract RAEs and promote more equitable physical and technical development in youth basketball players.

Table 1. Changes of COD deficit, YYIRT, CMJ, shooting, passing, and dribbling over time among CON and BG groups.

	CONq1q2 (n = 12) Baseline	CONq1q2 (n = 12) 6-month	CONq3q4 (n = 9) Baseline	CONq3q4 (n = 9) 6-month	BGq1q2 (n = 11) Baseline	BGq1q2 (n = 11) 6-month	BGq3q4 (n = 9) Baseline	BGq3q4 (n = 9) 6-month
COD deficit (s)	0.65 ± 0.19	0.54 ± 0.12	0.67 ± 0.08	0.65 ± 0.6	0.66 ± 0.14	0.55 ± 0.06	0.63 ± 0.15	0.54 ± 0.09
YYIRT (m)	448.3 ± 100.3	548.3 ± 93.2	442.2 ± 95.6	448.9 ± 89.5	443.6 ± 88.0	541.8 ± 74.0	444.4 ± 35.7	542.2 ± 40.6
CMJ (cm)	27.7 ± 2.7	30.6 ± 1.5	27.2 ± 2.0	28.1 ± 1.8	27.5 ± 2.8	30.7 ± 2.4	27.3 ± 1.5	30.0 ± 1.3
Shooting (n)	26.5 ± 1.6	29.7 ± 1.6	26.3 ± 1.9	27.0 ± 2.1	27.1 ± 2.0	30.3 ± 2.0	27.1 ± 2.3	30.4 ± 2.0
Passing (n)	91.3 ± 1.7	94.6 ± 1.8	90.8 ± 2.5	91.2 ± 3.1	91.1 ± 2.2	94.5 ± 2.4	90.6 ± 2.0	94.0 ± 2.0
Dribbling (n)	15.8 ± 0.4	15.2 ± 0.3	15.8 ± 15.7	15.8 ± 0.3	15.8 ± 0.4	15.2 ± 0.3	15.8 ± 0.4	15.2 ± 0.4

COD: change-of-direction; YYIRT: Yo-Yo intermittent recovery test; CMJ: countermovement jump; CON: control; BG: birthdate grouping; q1q2: birthdate between January and June; q3q4: birthdate between July and December.

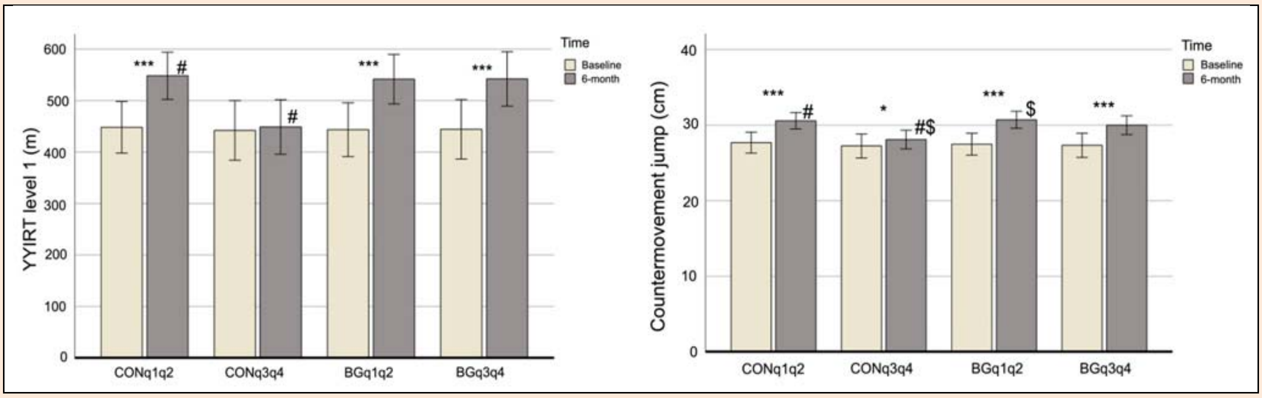

Figure 2. Baseline and post-6-month mean values and standard deviations for the Yo-Yo Intermittent Recovery Test (YYIRT) and countermovement jump performance between groups and birthdate quartiles. *Pre-post significant differences at $p < 0.05$; ***Pre-post significant differences at $p < 0.001$; #Between-group differences at $p < 0.05$; $Between-group differences at $p < 0.05$. CON: control; BG: birthdate grouping; q1q2: birthdate between January and June; q3q4: birthdate between July and December.

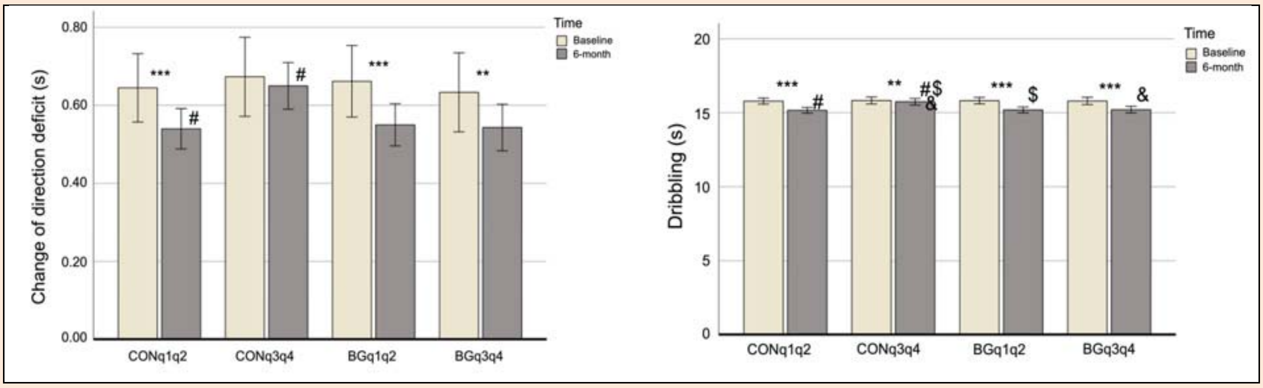

Figure 3. Baseline and post-6-month mean values and standard deviations for the change-of-direction (COD) and dribbling performance between groups and birthdate quartiles. **Pre-post significant differences at $p < 0.01$; ***Pre-post significant differences at $p < 0.001$; #Between-group differences at $p < 0.05$; $Between-group differences at $p < 0.05$; &Between-group differences at $p < 0.05$. CON: control; BG: birthdate grouping; q1q2: birthdate between January and June; q3q4: birthdate between July and December.

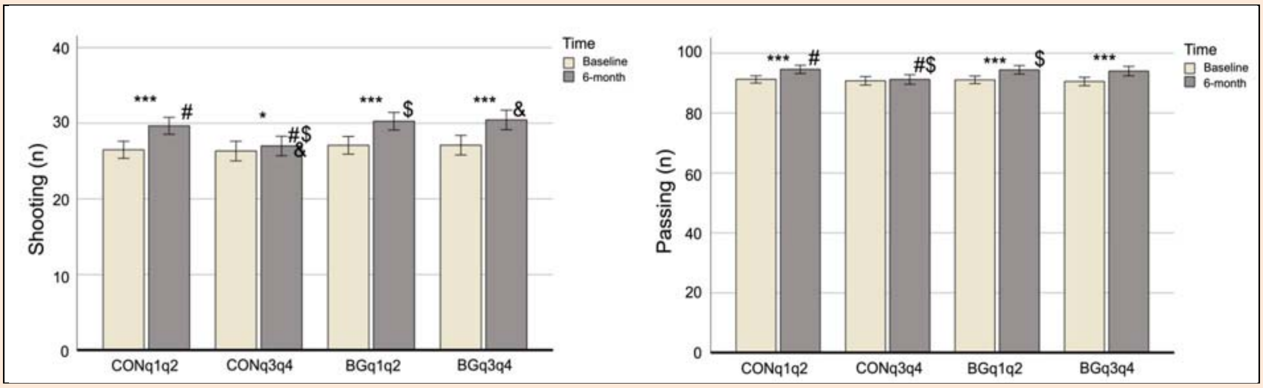

Figure 4. Baseline and post-6-month mean values and standard deviations for the shooting and passing performance between groups and birthdate quartiles. **Pre-post significant differences at $p < 0.01$; ***Pre-post significant differences at $p < 0.001$; #Between-group differences at $p < 0.05$; $Between-group differences at $p < 0.05$; &Between-group differences at $p < 0.05$. CON: control; BG: birthdate grouping; q1q2: birthdate between January and June; q3q4: birthdate between July and December.

Although previous studies suggest that the RAE does not affect the development of aerobic capacity and training in youth basketball players (Gonçalves and Carvalho, 2021), other research indicates that it does have an impact on both male and female basketball players (Gottlieb et al., 2023). Our research revealed that aerobic capacity was biased in the mixed-grouping approach, negatively impacting the development of players born in quartiles 3 and 4, who were unable to achieve the same progress as their peers in the CON group. Interestingly, in the BG group, players from both quartile groups (1 & 2 vs. 3 & 4) developed at a similar rate, with both showing significant improvements after six months and reaching comparable performance levels. Younger and relatively less mature players from quartiles 3 and 4 may have had fewer opportunities for high-intensity play and physical challenges, potentially limiting their aerobic development (Deprez et al., 2012). This aligns with previous findings on physiological stress in soccer matches (Vaeyens et al., 2005). In contrast, the BG group, where games were matched based on birthdate quartiles, likely provided more equitable competition and developmental opportunities within each quartile. This environment may have minimized the influence of maturity-related advantages, ensuring that aerobic capacity improvements were distributed more evenly across all quartiles (Cumming et al., 2017). Coaches may eventually use small-sided games that emphasize aerobic power, while grouping players by birthdate quartile and technical proficiency to adjust training stimuli.

In our findings, CMJ development was significantly lower for Q3/Q4 players in the mixed group, diverging from some prior studies. For instance, this is not aligned with a previous study which found that RAEs does not constrain the development of CMJ in youth basketball players (Gonçalves and Carvalho, 2021). However, if players born earlier in the year are generally taller and heavier (Rubajczyk et al., 2017), they may have a relative advantage in match scenarios or small-sided games, leading to a higher frequency of jumps and aerial duels. Over the course of the season, this advantage could ultimately impact the development of players born later in the year, who may engage in fewer such actions and consequently experience different physical adaptations.

Agility was a key finding in this study. Specifically, the physical component of agility, measured by the COD deficit, played a significant role when comparing CONq1q2 with CONq3q4. In contrast, for dribbling tasks requiring agility, CONq3q4 was significantly influenced by context, showing significantly worse performance than all other groups. One possible explanation for the COD deficit findings is that players born in the later quartiles (Q3 and Q4) may have had a relative disadvantage in strength and power - key determinants of COD ability (Papla et al., 2022). Since COD performance depends on lower-limb strength, rate of force development, and neuromuscular coordination, players in Q1 and Q2, who are generally more physically mature, may have had superior muscle mass and force production, allowing for more efficient directional changes (Pavillon et al., 2021).

Moreover, in the case of dribbling, this discrepancy likely arises from reduced exposure to high-quality, decision-rich game scenarios, potentially due to RAE-driven disparities in playing time, positional roles, and training intensity. Recommendations suggest that repeated exposure to complex, sport-specific situations enhances an athlete's ability to process visual cues, anticipate movements, and execute rapid motor responses (Spiteri, 2023). In traditional mixed-age competition settings (such as the control group), relatively younger players may receive fewer opportunities in high-intensity, high-pressure environments (Ibáñez et al., 2018), which may hinder their development of dribbling and agility. In contrast, the experimental group, which structured competition based on birthdate quartiles, may have provided a more equitable learning environment, ensuring all players engaged in agility-demanding situations at similar rates. For instance, a previous study (Chaouachi et al., 2014) on small-sided games and their impact on agility revealed that these games were effective in enhancing agility by improving dribbling and ball control proficiency. Another study found that players who developed agility through small-sided games were primarily positively impacted by improvements in recognition and perceptual aspects related to the agility task (Young and Rogers, 2014). This may suggest that contextual factors, such as equitable competition structures, play a crucial role in fostering agility development, particularly for players typically disadvantaged by RAE.

In shooting and passing, players born in quartiles 3 and 4 in mixed-grouping contexts showed limited development in these skills. Specifically, in shooting, this gap was evident across all comparison groups. Players born earlier in the selection year (Q1 and Q2) are often stronger and more physically developed (Rubajczyk et al., 2017), allowing them to generate greater shot power and stability, which may lead to more frequent shooting opportunities and, consequently, greater technical refinement over time. In contrast, players from Q3 and Q4, who are often at a relative disadvantage in strength (Rubajczyk et al., 2017), may struggle to execute shots, potentially leading to lower confidence and fewer attempts in game situations.

For passing, the disparities observed in mixed-grouping conditions could stem from game involvement and decision-making exposure. In traditional team dynamics, physically dominant players tend to assume central playmaking roles (Moselhy, 2023), receiving more touches and making more passing decisions. This eventually reinforces their perceptual-motor skills (Jose Figueiredo de Souza et al., 2024). Conversely, less mature players (Q3 and Q4) might receive fewer passes, or have limited involvement in playmaking sequences, restricting their opportunities to refine passing accuracy and decision-making. Balancing participation can not only enhance individual involvement but also improve psychological aspects, engagement, and enjoyment during the drills (Los Arcos et al., 2015).

This study has several limitations that should be acknowledged. First, the sample was limited to youth basketball players, so the findings may not generalize to other age groups, competitive levels, or sports with different physical and tactical demands. Additionally, maturation status was not directly considered when grouping players, meaning that differences in biological age within quartiles may have contributed to performance disparities. Furthermore, due to practical constraints, it was not possible to ensure a consistent training process across all remaining court sessions, which may have introduced variability in the training. Future research should explore the long-term effects of birthdate-based grouping across multiple seasons and investigate its impact on performance development. Additionally, combining assessments of relative age and biological maturation could provide a more nuanced understanding of developmental equity in training environments. Finally, assessing technical, tactical, and physiological demands over training sessions would provide deeper insights into the mechanisms of adaptation.

The findings of this study highlight the importance of structuring youth basketball training and competition to account for relative age effects, aiming to avoid unintentional bias caused by the current stage of maturation in coach selection. Coaches and sports organizations should consider grouping players based on birthdate quartiles to create more equitable developmental opportunities, particularly for those born later in the selection year. For instance, within a team, coaches may consider grouping players born in similar quartiles and incorporating small games or skill-based drills where their participation is higher. These activities could help mitigate the physical effects of RAE, particularly during specific moments of training, such as after warm-up or even during the warm-up itself. This approach can help balance physical and technical growth, ensuring that all athletes receive adequate game exposure and skill development.

Conclusion

This study signals that relative age effects significantly influence the physical and technical development of youth basketball players when training in mixed birthdate groups. Players born in the later quartiles (Q3 and Q4) exhibited slower progress in key performance measures, including COD, aerobic capacity, jumping ability, and technical skills such as shooting, passing, and dribbling. However, when athletes were grouped based on birthdate quartiles, development was more balanced, reducing disparities and ensuring more equitable progression. While our study fills a gap in the research, particularly regarding mitigation strategies for the RAE effect in basketball training, these findings highlight the need for age-sensitive training structures to optimize player development and minimize the disadvantages faced by relatively younger athletes. Implementing birthdate-based grouping strategies may help foster a more inclusive and competitive environment in youth basketball.

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Key points

- Structured birthdate quartile grouping improved physical performance (jump height, change-of-direction, and aerobic capacity) compared to mixed-quartile training.
- Technical skill development (shooting, passing, and dribbling) was significantly enhanced in quartile-based training groups, reducing RAE-related disparities.
- Mitigating the Relative Age Effect through targeted player matching promotes more equitable athlete development in youth basketball.

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