Research Square

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Longitudinal in-season changes in athletic performance of young professional basketball players

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Abstract

Background

Athletic performance testing is an important component of athlete monitoring and development in professional basketball. However, limited evidence is available on how different athletic performance capacities change longitudinally across a competitive season, particularly in young professional players transitioning into senior-level basketball. Therefore, this study investigated in-season changes in key athletic performance metrics and differences according to playing position in young professional basketball players.

Methods

Seventeen young professional male basketball players (mean age = 18.8 ± 2.5 years) were assessed longitudinally across the 2023/24 season at four predefined time points. Key performance metrics included upper-body muscular strength endurance (pull-ups), broad jump, 20 m-split time of the 3/4-court sprint, Lane Agility Test, and Yo-Yo Intermittent Recovery Test Level 2. Longitudinal changes were analyzed using separate linear mixed-effects models with time point and playing position as fixed effects. Significant time effects were followed by Bonferroni-adjusted pairwise comparisons, and effect sizes were expressed as partial eta square.

Results

Upper-body muscular strength endurance improved significantly across the season ($p < .001$, $\eta^2p = 0.53$), with improvements occurring mainly during the preparatory phase and being maintained thereafter. Change-of-direction performance also improved significantly over time ($p < .001$, $\eta^2p = 0.34$), with the best performance observed towards the end of the regular season. In contrast, broad jump performance ($p = .399$), sprint performance ($p = .274$), and intermittent endurance capacity ($p = .053$) remained stable over time. Significant positional differences were observed for pull-up performance ($p < .001$), sprint performance ($p = .012$), Lane Agility Test performance ($p < .001$), and Yo-Yo Intermittent Recovery Test Level 2 performance ($p < .001$), with perimeter players consistently outperforming interior players.

Conclusions

Most athletic performance parameters remained relatively stable across the competitive season in young professional basketball players, whereas upper-body muscular strength endurance and change-of-direction performance demonstrated longitudinal improvements. In addition, clear positional differences highlight the importance of position-specific performance profiling and longitudinal in-season monitoring strategies.

Trial registration:

German Clinical Trials Register (DRKS00032713, Date: 19/10/2023)

BACKGROUND

In professional sports, the systematic assessment of targeted performance parameters represents an important component of athlete monitoring and long-term performance development [1, 2]. Data obtained from functional screenings and performance tests are commonly used to evaluate training adaptations and to identify athletes potentially at increased risk of injury [3, 4]. Accordingly, a variety of testing and screening protocols are implemented in professional sports. The selection of appropriate assessments depends on factors such as athlete compliance, available resources, timing within the seasonal cycle, and sport-specific demands [5–7].

Basketball is characterized by highly intermittent movement patterns involving repeated accelerations and decelerations, changes of direction, jumping actions, and short maximal or near-maximal sprint efforts [8–10]. Consequently, players must possess well-developed neuromuscular and physical capacities to cope with the considerable physiological and mechanical demands of competition. The assessment of athletic performance therefore represents an important component of athlete evaluation and development in basketball [5, 11].

Participation in professional sports is typically contingent upon the successful completion of pre-competition medical assessments (PCMA) [7, 12]. Complementing medical clearance, sport-specific athletic performance is commonly evaluated using standardized testing protocols designed to reflect the movement demands of basketball. Such tests are typically conducted at defined time points to establish baseline values and to monitor physiological and functional adaptations to training [13].

The National Basketball Association (NBA) Draft Combine represents one of the most widely used testing batteries in basketball and has become a reference framework for performance testing in the sport [13]. In addition, several basketball-specific assessments have been developed to better reflect movement patterns observed during game situations. Despite these efforts, the standardization of testing batteries in basketball remains challenging [11].

Although performance testing is routinely implemented in professional basketball, most available studies are cross-sectional or limited to pre- versus post-season comparisons, with few employing repeated longitudinal assessments across the full competitive season [11, 14]. Consequently, little is known about how multiple athletic performance capacities develop throughout a competitive season, particularly in young professional players transitioning into senior-level basketball. Understanding these seasonal trajectories may support the optimization of monitoring strategies and position-specific training interventions. Repeated assessments across different phases of the season may provide a more detailed understanding of seasonal performance trajectories. Therefore, the aim of this study was to

investigate in-season changes in key athletic performance metrics across a competitive season in young professional basketball players competing in the German professional basketball system.

METHODS

Study Design

This prospective longitudinal observational study aimed to investigate in-season changes in athletic performance across the 2023/24 competitive season in young professional male basketball players competing in the German professional basketball system. Data were collected between August 2023 and April 2024 within a single professional men's basketball club. Performance testing was conducted at four predefined time points aligned with the seasonal training and competition schedule: at the beginning of the pre-season period (time point 1, TP1), after completion of the preparatory phase (time point 2, TP2), prior to the winter break (time point 3, TP3), and towards the end of the regular season before the start of the playoffs (time point 4, TP4). This design enabled the longitudinal assessment of changes in key athletic performance parameters across the season. TP1 and TP3 were performed on a Monday preceded by a rest day, TP2 (Monday) and TP4 (Wednesday) preceded a training day with low load. Load monitoring was performed continuously throughout the whole study period using the Session-Rating of perceived Exertion (RPE) method with an 11-point Category Ratio (CR-10) scale [15, 16].

At the beginning of the season, all players underwent a PCMA as part of routine medical clearance. The study was conducted in accordance with the Declaration of Helsinki, approved by the local ethics committee of the University of Bayreuth (approval no. 23–027), and registered in the German Clinical Trials Register (DRKS00032713, Date: 19/10/2023).

Participants

Participants were recruited from one professional men's basketball team competing in the German professional basketball system during the 2023/24 season. Initially, 19 players participated in the data collection. All athletes received detailed information about the study procedures and provided written informed consent prior to participation. For underage players, consent was additionally obtained from a legal guardian.

For the final statistical analysis, data from 17 players were included. Two players were excluded because they were not part of the team roster for the entire season or did not complete at least two performance testing sessions required for longitudinal analysis. Inclusion criteria were successful completion of the PCMA and participation in at least two of the four scheduled performance testing sessions. A formal a priori sample size calculation was not performed, as the study aimed to include the complete team roster within this field-based investigation.

Training schedule

As the present investigation employed a purely observational design, no modifications were made to either the competitive calendar or the habitual training process by the research team. During the in-season period, the weekly microcycle generally consisted of six training days and one scheduled rest day (Sunday). Training sessions were organized and supervised by the coaching staff and incorporated components of strength and conditioning, technical skill development, and team-tactical practice. Official competitive fixtures were typically held on Saturdays, followed by a consistently designated passive recovery day on Sundays [16].

Performance testing procedures

Athletic performance was assessed using a standardized basketball-specific testing battery implemented as part of the club's routine performance monitoring program. The battery included assessments of upper body muscular strength, jumping and sprinting performance, change-of-direction performance, and intermittent endurance commonly used in basketball performance diagnostics. A detailed overview of the entire testing battery is presented in Table 1.

Table 1
Overview of the complete performance testing battery.

Performance domain	**Performance test**
Strength	Bench press
	Pull-up
	Isometric mid-thigh pull
Jump and hop	Standing reach
	No-step vertical reach
	Maximum vertical reach
	Broad jump
	Single-leg hop for distance*
	Single-leg triple hop for distance*
	Single-leg triple crossover hop for distance*
	Lateral bound*
Sprint	*3/4-court sprint* with 5 m, 10, *20 m*, and 22.86 m *split times*
Change-of-direction	*Lane Agility Test*
Intermittent endurance	*Yo-Yo Intermittent Recovery Test Level 2*

For the purposes of the present study, analyses focused on a subset of established key performance outcomes representing distinct physical performance domains relevant to basketball performance. These included upper-body muscular strength endurance (pull-ups), lower-body explosive power (broad jump), linear sprint performance (20 m-split time during the 3/4-court sprint), change-of-direction performance (LAT), and intermittent endurance capacity (Yo-Yo IR2). These variables served as the primary outcome measures for the longitudinal analysis.

All testing sessions were conducted under standardized conditions at the club's training facilities on the same basketball court surface. Identical test procedures, test order, warm-up routines, equipment, instructions, standardized verbal encouragement provided by the testing staff, and recovery intervals were applied across all assessment time points. To minimize the influence of accumulated fatigue, performance assessments were scheduled on dedicated testing days without additional training exposure and were preceded by either a reduced training load or complete rest. For tests involving repeated attempts, three trials were performed, with the best performance retained for further analysis.

Upper-body muscular strength endurance

Upper-body muscular strength endurance was assessed using the maximum number of pull-ups performed with a pronated grip. Athletes performed the exercise using body weight only and were instructed to complete as many repetitions as possible while maintaining a full range of motion.

Jump performance

Lower-body explosive power was assessed using the broad jump, a widely used measure of horizontal power in basketball athletes [17–19]. Participants performed a bilateral jump from a standing position with a self-selected countermovement and free arm swing. Jump distance was measured from the starting line to the heel of the rearmost foot upon landing. Trials involving foot dragging or failure to achieve a stable bilateral landing without additional steps were considered invalid.

Sprint performance

Linear sprint performance was assessed using a 3/4-court sprint (22.86 m) with electronic timing gates (Witty, Microgate, Bolzano, Italy). Participants performed a stationary standing start with one foot positioned at the starting line and self-initiated the sprint by crossing the start gate. Split times were recorded at 5 m, 10 m, 20 m, and 22.86 m from the start line, with the 20 m split time used for subsequent analysis.

Change-of-direction performance

Change-of-direction performance was assessed using the LAT, a standardized test commonly used in basketball performance testing [20, 21]. Although originally developed to assess agility, the test primarily reflects pre-planned change-of-direction speed due to its fixed movement pattern. The test layout followed official basketball court dimensions and required athletes to sprint, shuffle, and backpedal around the key area. A detailed schematic and testing protocol are provided in the Appendix.

Intermittent endurance performance

Intermittent endurance capacity was evaluated using the Yo-Yo Intermittent Recovery Test Level 2 (Yo-Yo IR2), which assesses the ability to repeatedly perform high-intensity running efforts combined with short recovery periods and has demonstrated validity in elite team-sport populations [22]. The test consisted of repeated 2 × 20-m shuttle runs performed at progressively increasing speeds dictated by standardized audio signals, interspersed with 10 s of active recovery over a 2 × 5-m distance. Participants started with one foot positioned behind the starting line and initiated each shuttle in response to the audio signal. The test was terminated when a participant twice failed to reach the required line in time with the audio signal or voluntarily stopped due to exhaustion. Total distance covered was recorded as the outcome measure [23].

Player categorization

For analytical purposes, players were categorized according to their primary playing position into perimeter players (positions 1–3) and interior players (positions 4–5).

Statistical analysis

Raw data were collected in Microsoft Excel for Mac (version 16.103) and imported into IBM SPSS Statistics (version 31.0.0.0) for statistical analysis. Descriptive statistics are presented as absolute and relative frequencies for nominal variables and means with standard deviations (M ± SD) for continuous variables. Distributional assumptions for continuous variables were assessed using visual inspection of histograms and Q-Q plots, as well as the Shapiro-Wilk test.

The five key performance metrics were selected a priori based on their practical relevance in basketball performance diagnostics and their representation of distinct physical performance domains. Baseline Pearson correlation analyses were subsequently used to ensure that selected variables represented sufficiently distinct performance constructs and did not demonstrate excessive redundancy ($r \geq .75$).

Separate linear mixed-effects models (LMEMs) were fitted for each key performance metric to examine the effects of time and playing position. Time point was treated as a repeated effect within players, with a first-order autoregressive covariance structure used to account for the temporal dependency of repeated observations within individuals. Random intercepts for player ID were included when supported by improvements in model fit relative to fixed-effects-only models, as indicated by lower Akaike's Information Criterion (AIC) and Schwarz' Bayesian Information Criterion (BIC) values. Fixed effects were entered sequentially, beginning with time point, followed by playing position (perimeter vs. interior), and

finally the time point × position interaction. Interaction terms were retained when associated with improved model fit and meaningful contribution to model interpretation. Models were estimated using restricted maximum likelihood (REML). Statistical inference for fixed effects was based on Type III tests, with denominator degrees of freedom estimated using the Satterthwaite approximation. When a significant main effect of time point was observed, Bonferroni-adjusted pairwise comparisons of estimated marginal means were performed to identify differences between time points. Effect sizes for fixed effects were quantified using partial eta squared (η^2_p). Magnitudes were interpreted according to conventional thresholds adapted from Cohen, with values < 0.01 considered trivial, 0.01–0.059 small, 0.06–0.139 medium and > 0.14 large. Estimated marginal mean differences (ΔEMM) with 95% CIs were reported to facilitate applied interpretation. A two-sided α level of .05 was considered statistically significant for all analyses.

RESULTS

Athletic performance at baseline

Participants´ characteristics and the results of the key performance tests at baseline (TP1) are shown in Table 2.

Table 2

Participants characteristics and key performance metrics at baseline (TP1). Data are shown for the total cohort and stratified by playing position (perimeter vs interior players).

Characteristic / Key performance metric, unit(s)	**Total cohort** **n = 17**	**Perimeter players** **n = 11**	**Interior players** **n = 6**
Age, years	18.80 ± 2.50	18.90 ± 2.80	18.50 ± 2.10
Body height, cm	193.94 ± 10.23	188.36 ± 7.34	204.17 ± 5.71
Body weight, kg	90.25 ± 13.70	82.37 ± 5.23	104.86 ± 12.64
Pull-up, repetitions	7.76 ± 4.34	10.09 ± 3.18	3.50 ± 2.51
Broad jump, cm	243.76 ± 20.98	249.36 ± 22.70	233.50 ± 13.50
3/4-court sprint (20 m-split time), s	3.19 ± 0.18	3.12 ± 0.19	3.30 ± 0.09
Lane Agility Test, s	12.10 ± 0.65	11.77 ± 0.49	12.69 ± 0.45
Yo-Yo Intermittent Recovery Test Level 2, m	501.18 ± 210.29	614.55 ± 170.90	293.33 ± 54.65

Notes: Data are mean ± standard deviation. **Abbreviations**: TP Time point.

Among the key performance metrics – pull-up, broad jump, 20 m-split time of the 3/4-court sprint, LAT, and Yo-Yo IR2 – no pairwise baseline correlation exceeded r = 0.75 (see Supplementary Table S1), supporting their inclusion in subsequent LMEMs.

Longitudinal linear mixed-effects model outcomes

Upper-body muscular strength endurance improved significantly across the season ($p < .001$, $\eta^2_p = .53$), with gains occurring during the pre-season and maintained throughout the regular season. Playing position had a significant effect on pull-up performance ($p < .001$, $\eta^2_p = .59$), with perimeter players outperforming interior players. Jump performance did not change significantly over time ($p = .399$). Differences between perimeter and interior were not statistically significant ($p = .071$). Sprint performance did not change significantly over time ($p = .274$) but differed significantly by playing position ($p = .012$, $\eta^2_p = .36$), with perimeter players demonstrating faster sprint times. LAT performance improved significantly across the season ($p < .001$, $\eta^2_p = .34$), with the best performance observed at the end of the regular season. Perimeter players performed significantly better than interior players ($p < .001$, $\eta^2_p = .56$). Intermittent endurance performance did not change significantly over time ($p = .053$) but differed significantly by playing position ($p < .001$, $\eta^2_p = .73$), with perimeter players demonstrating higher intermittent endurance capacity. Results of the LMEMs are summarized in Table 3.

Table 3
Linear mixed-effects models for key performance tests.

Outcome	Effect	*F*(df1, df2)	*p* value	η^2	ΔEMM (95% CIs)
Pull-up	Time	*F*(3, 28.751) = 10.807	< .001***	0.53	Pre–post pre-season: 1.30 reps (0.09–2.51)
	Position	*F*(1, 15.274) = 22.323	< .001***	0.59	Perimeter – interior: 6.97 reps (3.83–10.11)
	Time × position	–	–	–	–
Broad jump	Time	*F*(3, 41.151) = 1.008	.399	–	–
	Position	*F*(1, 15.632) = 3.760	.071	–	–
3/4-court sprint	Time	*F*(3, 32.114) = 1.355	.274	–	–
(20 m-split time)	Position	*F*(1, 14.889) = 8.233	.012*	0.36	Perimeter – interior: 0.22 s (0.06–0.39)
Lane Agility Test	Time	*F*(3, 38.282) = 6.749	< .001***	0.34	TP3 – TP4: 0.72 s (0.25–1.19)
	Position	*F*(1, 15.096) = 19.308	< .001***	0.56	Perimeter – interior: 0.80 s (0.41–1.19)
	Time × position	–	–	–	–
Yo-Yo IR2	Time	*F*(3, 38.278) = 2.799	.053	–	–
	Position	*F*(1, 18.374) = 10.818	< .001***	0.73	Perimeter – interior:

Notes: ΔEMM values represent estimated marginal means differences. For time effects, ΔEMM reflects statistically significant pairwise comparisons following Bonferroni adjustment. η^2 denotes partial eta squared derived from the *F* statistics (df = degrees of freedom) of fixed-effects Type III tests. *p* values are two-sided. Significance levels: *p* < .05*, *p* < 0.01**, *p* < .001***. **Abbreviations**: CIs Confidence intervals. TP Time point.

Outcome	Effect	*F*(df1, df2)	*p* value	η^2	ΔEMM (95% CIs)
					300.47 m (210.18–390.77)

Notes: ΔEMM values represent estimated marginal means differences. For time effects, ΔEMM reflects statistically significant pairwise comparisons following Bonferroni adjustment. η^2 denotes partial eta squared derived from the *F* statistics (df = degrees of freedom) of fixed-effects Type III tests. *p* values are two-sided. Significance levels: $p < .05$*, $p < 0.01$**, $p < .001$***. **Abbreviations**: CIs Confidence intervals. TP Time point.

DISCUSSION

The present study demonstrated that only selected physical performance outcomes changed across the season, whereas most remained relatively stable. Upper-body muscular strength endurance improved substantially during the preparatory phase and was subsequently maintained throughout the competitive period. Similarly, change-of-direction performance improved across the season, with the best performance observed towards the end of the regular season. Collectively, these findings indicate that certain physical capacities may remain responsive during the competitive season despite ongoing training and match demands.

The observed improvement in upper-body muscular strength endurance during the preparatory phase followed by maintenance throughout the competitive season is consistent with previous findings in team sport athletes [24]. Similarly, Ferioli et al. [25] reported that the largest improvements in physical performance capacities in basketball players occurred during the preparatory period, whereas most athletic parameters remained comparatively stable throughout the competitive season. From an applied perspective, these findings suggest that change-of-direction ability and upper-body muscular strength endurance may represent useful monitoring variables during the season, as both demonstrated detectable longitudinal adaptations (upper-body muscular strength endurance: $\eta^2 = .53$; change-of-direction performance: $\eta^2 = .34$) while other performance metrics remained comparatively stable. This interpretation is further supported by recent findings indicating that change-of-direction assessments demonstrate high sensitivity for detecting seasonal performance changes in team-sport athletes [26]. Comparable findings have also been reported in basketball players, where change-of-direction performance improved despite limited changes in sprint and jump performance [27].

In contrast, jump and sprint performance remained stable across all time points. Similar findings have been reported previously in basketball and other team sports, where maximal sprint and jump capacities were largely maintained throughout the competitive period [5, 11, 27–30]. Chiang et al. [30] demonstrated that countermovement jump height improved following the preparatory phase and was subsequently maintained during the season, whereas 20 m-sprint performance remained unchanged. Likewise, Philipp et al. [29] observed stable jump height across a competitive basketball season despite alterations in underlying force-time characteristics. Collectively, these findings suggest that maximal neuromuscular capacities are generally maintained rather than substantially enhanced during the competitive season. However, alternative explanations such as ceiling effects, or limited statistical

power should also be considered. One possible explanation is that the neuromuscular training stimulus applied during the competitive season may have been insufficient to elicit further improvements in maximal sprint and jump performance.

Intermittent endurance performance likewise remained relatively stable across the season. Although the mechanisms underlying this stability cannot be determined from the present study, previous research suggests that the magnitude of training-induced adaptations is influenced by the athletes' initial fitness level, with lower-fit athletes exhibiting substantially greater improvements in aerobic and neuromuscular performance capacities than fitter players [31]. Similarly, Laursen and Jenkins highlighted that highly trained athletes often require particularly intensive training stimuli to elicit further physiological adaptation [32].

Clear positional differences were observed across several performance domains, with perimeter players outperforming interior players in upper-body muscular strength endurance, sprint performance, change-of-direction ability, and intermittent endurance capacity. These findings are consistent with previous research demonstrating distinct position-specific physical and locomotor demands in basketball [9, 10, 33, 34]. Perimeter players are typically exposed to greater high-speed locomotor demands and repeated directional changes [9, 34], which may contribute to their superior performance in speed-, change-of-direction-, and endurance-related tests. In contrast, the physical profile of interior players reflects position-specific demands that rely less on repeated high-speed movement actions.

These findings highlight the importance of interpreting performance data within the context of positional demands and support the implementation of position-specific training strategies in professional basketball [35, 36]. Rather than relying solely on isolated test results, practitioners should consider longitudinal changes in performance parameters when evaluating athlete development and training responses across the season.

Several limitations should be considered when interpreting the present findings. First, the relatively small sample size and inclusion of players from a single professional team may limit the generalizability of the results and reduce statistical power to detect smaller longitudinal effects [37]. Second, contextual factors such as external and internal load, recovery strategies, and travel demands were not incorporated into the statistical models and may have influenced individual performance trajectories. In addition, the observational study design precludes causal inferences regarding the mechanisms underlying the observed performance changes. Finally, the analysis focused on a preselected subset of performance indicators representing distinct physical performance domains relevant to basketball. While this approach reduced redundancy and improved interpretability, it does not capture all dimensions of athletic performance. Nevertheless, the longitudinal design with repeated measurements across different phases of the full basketball season and the use of basketball-specific performance assessments provide relevant applied insights into in-season athletic performance development in young professional basketball players.

CONCLUSIONS

Most athletic performance parameters in young professional basketball players remained relatively stable across the competitive season, indicating maintenance of key neuromuscular and intermittent endurance capacities under ongoing training and match demands. In contrast, upper-body muscular strength endurance and change-of-direction performance demonstrated longitudinal improvements, indicating that these performance domains may remain responsive throughout the competitive period. Furthermore, clear positional differences in athletic performance highlight the importance of position-specific performance profiling and of interpreting performance outcomes within the context of positional demands. Collectively, these findings support the implementation of structured longitudinal performance monitoring to track athlete development and guide position-specific training strategies across the competitive season.

Abbreviations

AIC Akaike's Information Criterion

AMS Athlete monitoring system

BIC Bayesian Information Criterion

CI Confidence interval

CR-10 Category ratio-10 scale

df Degrees of freedom

EMM Estimated marginal mean

LAT Lane Agility Test

LMEM Linear mixed-effects model

M Mean

NBA National Basketball Association

ns Not significant

PCMA Pre-competition medical assessment

REML Restricted maximum likelihood

RPE Rating of perceived exertion

SD Standard deviation

TP Time point

Yo-Yo IR2 Yo-Yo Intermittent Recovery Test Level 2

Declarations

Ethics approval and consent to participate.

The study was conducted in accordance with the most recent version of the Declaration of Helsinki, registered in the German Clinical Trials Register (ID: DRKS00032713, Date: 19/10/2023), and approved by the local ethics committee (University of Bayreuth, approval no. 23-027). Written informed consent was obtained from all participants or, in the case of adolescents, from their legal guardians after full disclosure.

Consent for publication.

Not applicable.

Availability of data and materials.

The datasets generated and/or analyzed in the current study are not publicly available but are available from the corresponding author on reasonable request.

Competing interests.

The authors declare that they have no competing interests.

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