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Cognitive Trajectories Across a Competitive Basketball Season in Youth Athletes and Non-Athlete Controls: A Three-Wave Longitudinal Study

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Highlights

What are the main findings?

- Small, nominally significant differences in seasonal change-detection trajectories were observed between basketball players and non-athlete controls.
- Basketball players showed within-group improvements in temporal estimation and motion anticipation, but the corresponding Time × Group interaction was not significant.

What are the implications of the main findings?

- Cognitive changes across the season were domain-specific, and basketball players and controls shared processing-speed improvements.
- The findings do not establish basketball-specific causal effects and support the use of longitudinal and ecologically valid assessments in future youth-sport research.

Abstract

Objectives: This three-wave longitudinal study examined intra-seasonal cognitive trajectories across a competitive basketball season in youth basketball players and age-comparable non-athlete controls. **Methods**: Ninety-one youth basketball players (U12, U14, U16) and 30 non-athlete controls completed computerized cognitive assessments at pre-season, mid-season, and post-season. Visuospatial attention (Change Detection Test [CDT]), motion anticipation (Timewall Test), and inhibitory control with processing speed (Flanker Task) were evaluated under standardized laboratory conditions. Primary athlete-control analyses combined the U12 and U14 cohorts (~U13), whereas U16 analyses were exploratory and included basketball players only because no age-comparable U16 control group was available. **Results**: Basketball players and non-athlete controls showed small, nominally significant differences in competitive seasonal change in visual attention and change-detection ability (p = 0.046, η^2 = 0.017) and response time (p = 0.020, η^2 = 0.025). Basketball players also showed within-season improvements in temporal estimation and

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motion anticipation ($p < 0.001$). Processing speed improved similarly in both groups, with no significant Time × Group interaction ($p = 0.92$), whereas Flanker accuracy ($p = 0.40$) and interference control ($p = 0.82$) showed no significant differential seasonal change. Exploratory U16 analyses showed no significant seasonal changes across the assessed cognitive domains (all $p > 0.05$). **Conclusions:** Cognitive performance changed selectively across the competitive season. Differences between basketball players and non-athlete controls were most evident in the seasonal pattern of change-detection performance. At the same time, basketball players also showed within-group improvements in temporal estimation and motion anticipation. Processing speed improved in both groups. Overall, the findings indicate domain-specific longitudinal cognitive changes but do not establish basketball-specific causal effects.

Keywords: youth basketball; visual attention; motion anticipation; inhibitory control; processing speed; cognitive trajectories

1. Introduction

Cognitive performance is a multidimensional construct encompassing processes such as attention, information processing speed, working memory, inhibitory control, cognitive flexibility, pattern recognition, temporal anticipation, and decision-making, suggesting that athletic success may not be attributable solely to physical capacity [1,2]. In open-skill dynamic team sports such as basketball, continuously evaluating changing environmental stimuli, suppressing distractors, and timely execution of appropriate motor responses may be particularly consequential [3–5]. This cognitive proficiency appears to facilitate generating alternative solutions in unpredictable game scenarios, while potentially enabling rapid execution of optimal motor responses even under high-stress conditions [6]. This phenomenon appears to reflect an integrated cognitive capacity frequently conceptualized as "game intelligence," which denotes an athlete's capability to read on-court situations, anticipate progression, and make strategic decisions accordingly [1].

Executive functions and general cognitive abilities are relevant to both sport-related cognitive performance [7,8] and academic functioning in youth [9–14]. Physical activity and sport participation have also been associated with broader developmental outcomes, including mental health [15] and academic performance [16–18].

Research on the impact of physical activity, exercise, and structured athletic training on cognitive performance has become increasingly prominent in recent years [19,20]. Systematic reviews conducted on children and adolescents report that physical fitness levels, acute exercise, and long-term physical activity programs display positive associations with attention, executive functions, and select academic performance indicators [21,22]. Nevertheless, these findings are not consistent across all cognitive domains, with effect sizes varying by exercise type, duration, frequency, intensity, and embedded cognitive demands [23,24]. Interventions that intentionally integrate physical movement with cognitive tasks "such as decision-making, rule-switching, stimulus selection, response inhibition, and movement planning" are posited to yield more pronounced executive function benefits [25]. A recent meta-analysis suggests that cognitively demanding physical activity programs may enhance executive functions in youth, with the most robust gains observed in inhibitory control and working memory [25]. Within this framework, basketball training may be more than a physiological load; it may serve as a complex cognitive-motor experience that demands continuous perception, timing, anticipation, response selection, and behavioral inhibition [26,27]. However, the cognitive advantage often seen in athletes compared to sedentary peers may not establish that sports training directly produces

these differences [28]. Factors such as age-related brain maturation, test familiarity over time, and natural baseline differences may influence the results [29]. In addition, cognitive performance across a competitive season may fluctuate in relation to training and competition demands, recovery status, and mental fatigue [30]. Because single-time-point assessments cannot capture within-person developmental trajectories, longitudinal tracking may better distinguish age-related cognitive development from patterns associated with prolonged sport exposure [31].

Therefore, this study aimed to examine cognitive performance longitudinally across a competitive basketball season and to determine whether seasonal trajectories differed between youth basketball players and age-comparable non-athlete controls. Specifically, we tested two main hypotheses: first, that youth basketball players would demonstrate significant within-group cognitive improvements from pre-season to post-season; and second, that this intra-seasonal cognitive progression would be greater in basketball players than in non-athlete controls across the assessed cognitive domains.

2. Materials and Methods

2.1. Participants

The study included 121 participants aged approximately 10–16 years. The sample comprised 91 youth basketball players and 30 age-comparable non-athlete controls, including 56 females and 65 males (Sex distribution by subgroup was as follows: U12 players, 23 females and 15 males; U14 players, 17 females and 18 males; U16 players, 18 males; U12 controls, 4 females and 4 males; and U14 controls, 12 females and 10 males). The basketball group included 38 [U12], 35 [U14], and 18 [U16] players, whereas the control group included 8 [U12] and 22 [U14] participants; no [U16] control group was available. We estimated age from year of birth, and U12, U14, and U16 referred to competitive basketball age-group classifications rather than exact chronological age at the date of assessment. Basketball players had 4.34 ± 1.99 years of training experience, and all players competed throughout the season and completed at least four basketball training sessions per week, each lasting about 1.5 h (≥6 h·week^{-1}), and typically participated in one competitive match per week. Control participants did not regularly participate in organized sports. Neither the basketball nor the control group engaged in cognitive training as part of their regular training regimen or daily life. According to self-reported data, none of the participants had a current diagnosis or history of depression, nor any neurological, psychiatric, or cardiovascular conditions. Furthermore, no participants were under regular pharmacological treatment during the study period. Participant availability and valid task data varied across the three assessment waves, resulting in outcome-specific longitudinal sample sizes. Longitudinal analyses were therefore based on complete cases for each cognitive outcome, and missing values were not imputed. Detailed reasons for all missing or invalid task observations were not systematically recorded.

The study was conducted in accordance with the ethical principles of the Declaration of Helsinki. Ethical approval was obtained from the Dokuz Eylül University Non-Interventional Ethics Committee (approval number: 10261-GOA 2025/37−14). Before participation, all participants were informed about the study's purpose and procedures. Participants provided written informed consent, and all minors provided written parental or legal consent.

2.2. Experimental Design

We used a prospective, controlled longitudinal design to examine changes in cognitive performance across one competitive basketball season (2025–2026). Assessments were conducted at three time points: pre-season in August 2025, mid-season in January 2026,

and post-season in June 2026. Consecutive measurements were separated by approximately five months. All cognitive assessments were computer-based and administered under standardized laboratory conditions. Following the methodological recommendations of Mancı et al. (2025), we rigorously controlled for procedural, circadian, and environmental confounders [32]. Participants were evaluated in the same testing environment, at the same time of day across all measurement waves, using standardized instructions. At each point, participants completed three computerized cognitive tasks via the Psychology Experiment Building Language battery (PEBL 2.1): the Change Detection Test, the Timewall Test, and the Flanker Task. The administration sequence of the three cognitive tasks was randomized across participants and then held constant within each participant across all three assessment waves. We applied the same randomization procedure to both groups. Before data collection at each time point, participants completed standardized practice trials under researcher supervision until task comprehension was established (a minimum of three practice repetitions). The same familiarization procedure was repeated at each assessment to standardize task understanding and reduce variability related to task unfamiliarity.

2.3. Cognitive Tests

Cognitive performance was assessed using three computerized tasks implemented through the Psychology Experiment Building Language test battery (PEBL, version 2.1). PEBL is an open-source platform designed to standardize the administration of behavioral and neuropsychological tasks and supports accurate recording of response accuracy and reaction time [33–35]. The Change Detection Test, Timewall Test, and Flanker Task were selected to provide complementary measures of distinct but interrelated cognitive abilities, including visuospatial attention, visual information processing, temporal estimation, selective attention, processing speed, and inhibitory control. These abilities may be relevant to a broad range of everyday and academic activities, such as detecting changes in the environment, sustaining attention, estimating the timing of events, filtering irrelevant information, responding efficiently, and suppressing inappropriate or competing responses. The selected tasks therefore allowed evaluation of cognitive performance across multiple domains without being specific to athletic experience or sport-related knowledge. The cognitive domains assessed by these tasks followed the methodological framework described by Mancı et al., 2025 [32].

The *Change Detection Test* used a flicker/change-blindness paradigm in which two nearly identical displays of colored circles alternated until the participant detected a change in color, size, position, or presence. The task assessed visuospatial attention, visual information processing, and change-detection performance [34,36]. The task consisted of 20 trials. The outcome variables were the total number of correct responses, ranging from 0 to 20, and the overall mean response time (seconds) across all trials. Response time was calculated by averaging the duration of all trials without separating correct and incorrect responses.

The *Timewall Test* was used to assess temporal estimation, motion prediction, and visuospatial perception. These abilities contribute to the prediction of when a moving event will occur and are relevant to many daily activities requiring accurate timing and anticipation [35,37,38]. During each trial, an object moved downward at a constant speed and became invisible before reaching a marked target point. Participants pressed a key when they estimated that the object had reached the target. Responses before the actual target time were classified as early, and responses after the target time were classified as late. A response was classified as "great accuracy" when the absolute difference between the actual target time and the participant's response was less than 0.05. The outcome variable was the number of great-accuracy responses across 20 trials. This threshold-based

score was the prespecified Timewall outcome used in the present study; continuous measures of timing error were not included in the original analysis.

The Flanker Task was used to assess selective attention, processing speed, interference control, and the ability to inhibit responses triggered by irrelevant stimuli [39]. These functions may be important for maintaining task focus and selecting an appropriate response when competing information is present [40,41]. The principal outcome variables were overall mean accuracy (%), overall mean reaction time (ms), and the flanker interference effect. Accuracy was recorded as a proportion and converted into a percentage for reporting. The interference effect was calculated by subtracting the mean reaction time for congruent trials from the mean reaction time for incongruent trials: [Flanker interference effect = $RT_{incongruent} - RT_{congruent}$]. A smaller interference score may indicate a lower response cost arising from conflicting information and, consequently, more efficient inhibitory control [39].

2.4. Statistical Analysis

All statistical analyses were performed using JASP software (JASP Software 0.98.1). Descriptive data were presented as means (M) and standard deviations (SD). Distributional assumptions were evaluated using skewness and kurtosis, with values within ±1.5 considered acceptable. When this criterion was exceeded, variables were retained in their original scale, and no post hoc transformation was applied; such findings were interpreted cautiously. Each cognitive outcome was analyzed separately. Repeated measures analyses were conducted using complete cases for the respective cognitive outcome; therefore, the number of participants included in the longitudinal analyses varied across outcomes. Missing values were not imputed. The primary inferential effect for the athlete-control comparison was the time-by-group interaction, which tested whether the pattern of seasonal change differed between basketball players and non-athlete controls. Holm-adjusted within-group pairwise comparisons were used to characterize the timing of change within each group and were not interpreted as evidence of a between-group difference. Age was entered as a continuous covariate in its original scale and was not mean-centered in the original models; Time × Age terms were included in the models but were not used as the primary basis for interpretation. Accordingly, the omnibus main effect of time was not used as the principal basis for substantive interpretation of the longitudinal findings. Competitive seasonal changes were examined using a mixed-design repeated-measures analysis of variance. Time, comprising the pre-season, mid-season, and end-of-season assessments, was entered as the within-subject factor, whereas group, comprising basketball players and non-athlete controls, was entered as the between-subject factor. Age was included as a covariate and sex as an additional between-subject factor; therefore, the analyses were adjusted for the potential effects of age and sex. The main effect of time represented the overall seasonal change, while the group-by-time interaction indicated whether the pattern of change differed between basketball players and non-athlete controls. Because no U16 control group was available, the primary comparisons between basketball players and controls were restricted to the U12 and U14 categories. Separate age-specific repeated-measures analyses were subsequently conducted for U12 players, U12 controls, U14 players, and U14 controls. U16 analyses were exploratory and included basketball players only because no U16 control group was available. Mauchly's test was used to assess the assumption of sphericity. Greenhouse-Geisser-corrected results were considered when this assumption was violated. Significant effects were followed by Holm-adjusted pairwise comparisons between pre-season, mid-season, and end-of-season measurements. Because multiple cognitive outcomes were examined and no single outcome was designated as the sole primary endpoint, time-by-group effects were interpreted in conjunction with their effect sizes and with appropriate caution regarding multiplicity. Holm

adjustment was applied to within-outcome pairwise comparisons but not across distinct cognitive outcomes. Statistical significance was set at $p < 0.05$, and effect sizes were reported using eta squared (η^2).

3. Results

3.1. Pre-Season Cognitive Performance

At the pre-season assessment, no statistically significant differences were observed between basketball players and non-athlete controls in any of the assessed cognitive outcomes within either the U12 or U14 age categories. No significant between-group differences were observed in CDT accuracy or response time, Timewall performance, Flanker accuracy, mean reaction time, or interference effect (all $p > 0.05$). Similarly, no significant baseline differences were found for any cognitive outcome in the pooled U12+U14 (~U13) cohort (all $p > 0.05$; Table 1).

Table 1. Pre-season cognitive performance characteristics of basketball players and non-athlete controls by age cohort.

Variable	U12 Players [N] (n = 38)	U12 Controls [N] (n = 8)	Sig. (t/p/d)	U14 Players (n = 35)	U14 Controls (n = 22)	Sig. (t/p/d)	Pooled U12+U14 (~U13) Players (n = 73)	Pooled U12+U14 (~U13) Controls (n = 30)	Sig. (t/p/d)
Age (years)	10.79 ± 0.41	11.25 ± 0.46	N/A	12.57 ± 0.50	12.64 ± 0.58	N/A	11.64 ± 1.01	12.27 ± 0.83	N/A
CDT correct responses (n)	11.38 ± 4.10	10.25 ± 2.96	t = 0.735; *p* = 0.46; d = 0.289	12.80 ± 3.59	11.45 ± 3.31	t = 1.420; *p* = 0.16; d = 0.386	12.10 ± 3.89	11.13 ± 3.21	t = 1.197; *p* = 0.23; d = 0.262
CDT mean response time (s)	14.45 ± 2.31	15.49 ± 3.35	t = −1.04; *p* = 0.30; d = −0.411	14.22 ± 3.90	15.35 ± 2.82	t = −1.178; *p* = 0.24; d = −0.322	14.33 ± 3.18	15.39 ± 2.91	t = −1.550; *p* = 0.12; d = −0.340
Timewall great accuracy (n)	7.13 ± 2.55	5.67 ± 2.42	t = 1.295; *p* = 0.20; d = 0.576	7.58 ± 2.78	9.27 ± 2.63	t = −1.962; *p* = 0.059; d = −0.617	7.35 ± 2.65	8.24 ± 3.02	t = −1.285; *p* = 0.20; d = −0.324
Flanker accuracy (%)	89.1 ± 12.4	86.7 ± 7.4	t = 0.462; *p* = 0.64; d = 0.206	95.3 ± 4.4	95.4 ± 2.7	t = −0.081; *p* = 0.93; d = −0.023	92.3 ± 9.7	93.5 ± 5.4	t = −0.599; *p* = 0.55; d = −0.138
Flanker mean reaction time (ms)	501.0 ± 57.9	508.4 ± 68.2	t = −0.278; *p* = 0.78; d = −0.124	473.5 ± 45.1	468.8 ± 42.3	t = 0.382; *p* = 0.70; d = 0.107	487.1 ± 53.2	477.6 ± 50.5	t = 0.787; *p* = 0.43; d = 0.180
Flanker interference effect (ms)	51.24 ± 18.45	44.76 ± 11.96	t = 0.749; *p* = 0.46; d = 0.366	47.36 ± 15.30	51.40 ± 20.53	t = −0.804; *p* = 0.42; d = −0.231	49.13 ± 16.77	50.07 ± 19.10	t = −0.224; *p* = 0.82; d = −0.054

CDT, Change Detection Test; RT, reaction time. The pooled U12+U14 cohort (~U13) represents the combined early-adolescent sample used for the primary athlete-versus-control analyses and does not constitute a separate age category. Age was not compared between groups in this table; age and sex were controlled in the primary longitudinal analyses. Values are presented as mean ± standard deviation. Between-group comparisons were performed using independent-samples Student's t-tests and are reported as t, p, and Cohen's d. [N] Note: Age was estimated from year of birth. Competitive age categories (U12, U14, and U16) were defined according to basketball age-group classifications and therefore do not correspond exactly to chronological age at the time of assessment. Table 1 includes all available pre-season observations, whereas Table 2 is based on outcome-specific complete cases with valid data at all three assessment waves; therefore, baseline means may differ slightly between the two tables.

Table 2. Competitive seasonal cognitive trajectories in the pooled U12+U14 cohort of basketball players and non-athlete controls.

Variable	U12-14 Players Pre/Mid/Post	U12-14 Controls Pre/Mid/Post	Time X Group Sig. (F/*p*/n^2)	Significant Holm-adjusted within-group comparisons
CDT correct responses (n) (n = 57/22)	12.56 ± 3.78/ 12.10 ± 3.14/ 14.16 ± 3.13	11.14 ± 3.14/ 12.95 ± 2.61/ 13.55 ± 4.04	F(2, 148) = 3.136; ***p* = 0.046**; η^2 = 0.017	Players: **Pre–Post *p* = 0.010; Mid–Post *p* < 0.001.** Controls: **Pre–Mid *p* = 0.028; Pre–Post *p* = 0.013**
CDT mean response time (s) (n = 58/23)	14.28 ± 3.32/ 15.10 ± 4.02/ 14.14 ± 4.11	15.38 ± 3.16/13.54 ± 3.44/15.21 ± 4.58	F(2, 152) = 3.999; ***p* = 0.020**; η^2 = 0.025	No Holm-adjusted within-group pairwise comparison reached significance.
Timewall great accuracy (n) (n = 58/21)	7.48 ± 2.68/ 9.62 ± 3.63/ 9.45 ± 3.27	8.24 ± 3.02/ 8.43 ± 2.73/ 9.29 ± 3.84	*F*(2, 148) = 2.429; *p* = 0.092**;** η^2 = 0.012	Players: **Pre–Mid *p* < 0.001; Pre–Post *p* < 0.001**. Controls: none
Flanker accuracy (%) (n = 52/26)	91.7 ± 10.6/ 93.7 ± 5.1/ 93.4 ± 6.0	93.5 ± 5.5/ 91.7 ± 9.5/ 93.2 ± 6.3	*F*(2, 146) = 0.901; *p* = 0.408; η^2 = 0.005	None
Flanker mean reaction time (ms) (n = 57/25)	485.0 ± 54.4/ 450.0 ± 53.8/ 434.8 ± 46.3	477.0 ± 52.5/ 448.7 ± 50.1/ 431.7 ± 35.6	F(2, 154) = 0.079; *p* = 0.924; η^2 < 0.001	Players: **Pre–Mid *p* < 0.001; Pre–Post *p* < 0.001; Mid–Post *p* = 0.017.** Controls: **Pre–Mid *p* = 0.023; Pre–Post *p* < 0.001; Mid–Post *p* = 0.040**
Flanker interference effect (ms) (n = 38/22)	54.19 ± 15.01/ 50.58 ± 18.61/ 43.90 ± 22.86	51.85 ± 19.25/ 50.48 ± 15.76/ 46.76 ± 18.78	F(2, 110) = 0.192; *p* = 0.825; η^2 = 0.002	None

Values are presented as mean ± standard deviation in pre-season (Pre), mid-season (Mid), and post-season (Post) order. F, F statistic; η^2, eta squared; CDT, Change Detection Test; RT, reaction time. Complete-case sample sizes are presented as basketball players/controls (n) for each outcome and represent participants with valid data at all three assessment waves.

3.2. Seasonal Cognitive Trajectories in the Pooled U12+U14 Cohort

In the pooled U12+U14 cohort, seasonal trajectories differed between basketball players and non-athlete controls for selected cognitive outcomes after controlling for age and sex. Nominally significant time-by-group interactions with small effect sizes were observed for CDT correct responses, F(2, 148) = 3.136, $p = 0.046$, $\eta^2 = 0.017$, and CDT mean response time, F(2, 152) = 3.999, $p = 0.020$, $\eta^2 = 0.025$. For CDT correct responses, the significant time-by-group interaction reflected different temporal patterns across the season. Basketball players improved from pre- to post-season ($p = 0.010$) and from mid- to post-season ($p < 0.001$), whereas controls improved from pre- to mid-season ($p = 0.028$) and from pre- to post-season ($p = 0.013$). No significant time-by-group interactions were observed for Timewall performance, Flanker accuracy, Flanker mean reaction time, or the Flanker interference effect (Table 2). For Timewall performance, basketball players showed significant within-group improvements from pre-season to mid-season and from pre-season to post-season; however, these within-group changes were not accompanied by a significant time-by-group interaction and were therefore not interpreted as evidence of a differential athlete-control trajectory. For Flanker mean reaction time, significant reductions were observed within both basketball players and controls, while the time-by-group interaction remained non-significant, indicating a shared temporal pattern rather than a group-specific change. This shared reduction is compatible with a possible repeated-testing or task-learning effect. In addition, for CDT mean response time, no Holm-adjusted within-group pairwise comparison reached statistical significance despite the significant overall time-by-group interaction, indicating a difference in trajectory shape rather than a consistent directional improvement in either group. The CDT response-time

interaction was further qualified by a significant time-by-group-by-sex interaction, F(2, 152) = 4.375, p = 0.014, η^2 = 0.027. Descriptively, the temporal pattern differed between females and males across the player and control groups (players: 27 females/31 males; controls: 12 females/11 males); given the modest sex-specific cell sizes, this interaction was considered exploratory and was not further decomposed inferentially.

3.3. Age-Specific Competitive Seasonal Changes in Cognitive Performance

Age-specific analyses for U12 and U14 players and controls are presented in Table 3. Given the small control subgroup sizes, these analyses were interpreted primarily as descriptive findings and were not used to infer between-group differences from differences in statistical significance. Exploratory U16 athlete-only results are presented in Table 4.

Table 3. Age-specific (U12 and U14) competitive seasonal changes in cognitive performance.

Variable	U12 Players Pre/Mid/Post	Sig. (F/*p*/n²)	U12 Controls Pre/Mid/Post	Sig. (F/p/n²)	U14 Players Pre/Mid/Post	Sig. (F/*p*/n²)	U14 Controls Pre/Mid/Post	Sig. (F/*p*/n²)
CDT correct responses (n)	12.28 ± 4.15/12.28 ± 3.06/ 14.64 ± 2.78	F(2,48) = 5.357; p = 0.008 **; η^2 = 0.182; **Pre–Post p = 0.023; Mid–Post p = 0.011**	10.25 ± 2.96/ 12.88 ± 3.04/ 14.38 ± 2.62	F(2,12) = 0.346; p = 0.715; η^2 = 0.020	12.78 ± 3.52/11.97 ± 3.25/13.78 ± 3.38	F(2, 62) = 5.048; **p = 0.009 **;** η^2 = 0.140; **Mid–Post p = 0.010 ***	11.64 ± 3.23/ 13.00 ± 2.45/ 13.07 ± 4.70	F(2,26) = 0.917; p = 0.412; η^2 = 0.066
CDT mean response time (s)	14.26 ± 2.26/14.48 ± 3.15/14.49 ± 4.59	F(2,50) = 0.700; p = 0.502; η^2 = 0.012	15.49 ± 3.35/ 12.98 ± 3.35/ 15.29 ± 5.72	F(2,12) = 1.297; p = 0.309; η^2 = 0.117	14.30 ± 4.07/14.65 ± 4.64/13.83 ± 3.68	F(2, 58) = 1.634; p = 0.204; η^2 = 0.024; **Sex: p = 0.042 ***	15.33 ± 3.18/ 13.84 ± 3.56/ 15.18 ± 4.07	F(2,26) = 0.506; p = 0.609; η^2 = 0.025
Timewall great accuracy (n)	7.32 ± 2.58/9.32 ± 3.91/9.14 ± 3.71	F(2,54) = 4.622; p = 0.014; η^2 = 0.146; **Pre–Mid p = 0.049 ***	5.67 ± 2.42/ 6.50 ± 2.59/ 7.33 ± 3.62	F(2,8) = 2.421; p = 0.151; η^2 = 0.123	7.63 ± 2.81/9.90 ± 3.40/9.73 ± 2.83	F(2, 58) = 9.353; p < 0.001 ***; η^2 = 0.244; **Pre–Mid p = 0.002 **; Pre–Post p < 0.001 *****	9.27 ± 2.63/ 9.20 ± 2.46/ 10.07 ± 3.75	F(2,26) = 0.937; p = 0.404; η^2 = 0.029
Flanker accuracy (%)	88.0 ± 13.3/93.4 ± 4.3/ 92.5 ± 6.1	F(2,50) = 2.878; p = 0.066; η^2 = 0.103	86.7 ± 7.4/ 82.5 ± 16.8/ 92.5 ± 5.8	F(2,8) = 1.293; p = 0.326; η^2 = 0.057; **Sex: p < 0.001 *****	95.3 ± 4.7/ 93.9 ± 5.8/ 94.2 ± 5.8	F(2, 48) = 2.235; p = 0.118; η^2 = 0.020; **Sex: p = 0.029;**	95.5 ± 2.6/ 94.5 ± 3.1/ 93.5 ± 6.5	F(2,36) = 0.238; p = 0.789; η^2 = 0.006
Flanker mean reaction time (ms)	500.6 ± 61.23/467.6 ± 56.68/443.3 ± 51.42	F(2,52) = 14.91; p < 0.001 ***; η^2 = 0.365; **Pre–Mid p = 0.012 *; Pre–Post p < 0.001 ***; Mid–Post p = 0.003 ****	508.4 ± 68.22/445.6 ± 65.54/430.3 ± 36.03	F(2,8) = 1.171; p = 0.358; η^2 = 0.145	471.0 ± 43.92/434.2 ± 46.41/427.2 ± 40.58	F(2, 58) = 13.64; p < 0.001 ***; η^2 = 0.320; **Pre–Mid p < 0.001 ***; Pre–Post p < 0.001 *****	467.0 ± 44.21/ 449.6 ± 46.30/ 432.2 ± 36.45	F(2,34) = 0.374; p = 0.691; η^2 = 0.006
Flanker interference effect (ms)	58.11 ± 15.38/56.44 ± 19.11/45.67 ± 23.47	F(2,30) = 3.032; p = 0.063; η^2 = 0.168	48.06 ± 10.88/54.27 ± 8.03/ 50.90 ± 22.46	F(2,4) = 0.135; p = 0.878; η^2 = 0.038	51.34 ± 14.41/46.32 ± 17.44/42.61 ± 22.87	F(2, 40) = 1.540; p = 0.227; η^2 = 0.048	52.69 ± 20.81/ 49.64 ± 17.07/ 45.84 ± 18.48	F(2,32) = 0.908; p = 0.414; η^2 = 0.026

Note: Values are presented as mean ± standard deviation in pre-season/mid-season/post-season order. Seasonal changes were examined using repeated-measures ANOVA. Significant pairwise comparisons are based on Holm-adjusted p-values. F, F statistic; η^2, eta squared; CDT, Change Detection

Test; RT, reaction time. Significant sex effects or time-by-sex interactions are reported where applicable. *p< 0.05, **p<0.01, ***p<0.001

Table 4. U16 basketball players' seasonal changes in cognitive performance.

Variable	U16 [N] Players Pre/Mid/Post	Sig. (F/p/n^2)
CDT correct responses (n)	14.93 ± 3.77/ 13.20 ± 2.62/ 16.00 ± 3.55	F(2, 28) = 3.292; p = 0.052; η^2 = 0.190
CDT mean response time (s)	12.06 ± 3.34/ 14.77 ± 4.86/ 15.42 ± 5.20	F(2, 30) = 2.707; p = 0.083; η^2 = 0.153
Timewall great accuracy (n)	9.87 ± 3.76/ 11.47 ± 3.98/ 10.13 ± 3.04	F(2, 28) = 1.187; p = 0.320; η^2 = 0.078
Flanker accuracy (%)	93.2 ± 6.5/ 93.1 ± 5.5/ 94.4 ± 3.1	F(2, 24) = 0.519; p = 0.602; η^2 = 0.041
Flanker mean reaction time (ms)	408.7 ± 42.45/ 401.9 ± 43.18/ 402.6 ± 38.42	F(2, 26) = 0.284; p = 0.755; η^2 = 0.021
Flanker interference effect (ms)	47.06 ± 13.24/ 42.49 ± 16.15/ 38.25 ± 19.19	F(2, 20) = 0.921; p = 0.414; η^2 = 0.084

Values are presented as mean ± standard deviation in pre-season (Pre), mid-season (Mid), and post-season (Post) order. [N] Note: U16 analyses were exploratory and included athletes only because no U16 control group was available; sex was not included in the U16 models because all U16 participants were male. F, F statistic; η^2, eta squared; SD, standard deviation; CDT, Change Detection Test; RT, reaction time; Pre, pre-season; Mid, mid-season; Post, post-season.

4. Discussion

This study aimed to examine how cognitive performance changes across a competitive season in youth basketball players and whether these changes differ from those observed in non-athlete controls. The longitudinal design may have enabled the evaluation of cognitive performance at three different points across the season (pre-season, mid-season, and post-season) rather than relying on a single assessment. Thus, the study may also help distinguish season-related cognitive changes from differences that may already be present at baseline or arise through normal age-related development.

At pre-season, no statistically significant athlete-control differences were observed across the assessed cognitive outcomes within the U12 or U14 categories or in the pooled U12+U14 cohort. However, the absence of statistically significant differences should not be interpreted as evidence of formal equivalence, particularly because some baseline effect sizes were not negligible. This pattern is consistent with the broader sport-cognition literature, in which differences between athletes and non-athletes vary across cognitive domains and task characteristics [2,4,42]. Baseline performance should therefore be considered as contextual information rather than as evidence that the groups were cognitively equivalent. Age and sex were included in the primary longitudinal analyses to reduce the influence of developmental differences between participants. The primary pooled analyses provided partial support for the hypothesis that seasonal trajectories would differ between groups. Nominal time-by-group interactions were observed for CDT correct

responses and CDT mean response time, although both effects were small and should be interpreted cautiously because multiple cognitive outcomes were examined without adjustment across distinct outcomes. For CDT correct responses, basketball players improved mainly during the second half of the season, whereas controls showed an earlier improvement. Because controls started from a somewhat lower mean CDT accuracy score and improved earlier, regression to the mean cannot be completely excluded as a contributor to this pattern. For CDT response time, no Holm-adjusted within-group pairwise comparison was significant, and the interaction was further qualified by a significant time-by-group-by-sex interaction. These findings therefore suggest different seasonal trajectories in change-detection performance rather than a consistent overall improvement specific to basketball players. Basketball players showed within-group improvements in temporal estimation and motion anticipation; however, the non-significant time-by-group interaction indicates that these changes were not significantly different from those observed in controls. Accordingly, the Timewall findings should not be interpreted as evidence that basketball training produced greater improvement than no training. Similarly, Flanker reaction time decreased in both groups without a significant time-by-group interaction. These patterns may reflect common time-related influences, including maturation and repeated task exposure, while variation in training and competition exposure, recovery status, and mental fatigue may also have contributed to cognitive performance across the season [43,44]. Flanker accuracy and interference effects remained relatively stable across the season, further indicating that seasonal changes were not uniform across the assessed cognitive domains.

Within-group analyses stratified by age category provide a more nuanced perspective on the intra-seasonal cognitive adaptations across early adolescence. Non-athlete controls in the U12 and U14 cohorts did not show statistically significant main effects of time across the assessed cognitive variables. However, given the small control subgroup sizes, these non-significant findings should not be interpreted as evidence of an absence of developmental change or as ruling out maturation as a contributor to the observed seasonal patterns. In U12 basketball players, intra-seasonal improvements were particularly prominent across three core domains: visual attention, motion anticipation, and processing speed. Specifically, correct responses on the Change Detection Test increased significantly across the season ($p = 0.008$), with post-season scores significantly surpassing both baseline ($p = 0.023$) and mid-season ($p = 0.011$) levels. Furthermore, these younger athletes exhibited substantial gains in Timewall estimation accuracy ($p = 0.014$) and a progressive shortening of Flanker mean reaction times across all consecutive testing intervals ($p < 0.001$). A broadly comparable seasonal pattern was observed among U14 players who similarly demonstrated significant seasonal enhancements in CDT accuracy ($p = 0.009$; particularly from mid-to-post season, $p = 0.010$), Timewall temporal accuracy ($p < 0.001$), and Flanker response latencies ($p < 0.001$). This shared developmental profile may align with the perceptual-cognitive and motor demands characteristic of invasive team sports. Open-skill environments such as basketball typically require continuous, rapid visual scanning of dynamic teammates, opponents, and ball trajectories, alongside precise spatial-temporal anticipation and immediate execution of motor adjustments. Empirical evidence suggests that visual attention capacity and temporal anticipation are particularly plastic and sensitive to structured athletic regimes, underpinning perceptual-cognitive expertise in team disciplines [4,45]. These findings occurred during a developmental period characterized by continuing maturation of executive and attentional processes, which may interact with repeated cognitively demanding sport exposure [21,22,46,47]. Conversely, CDT response latency, Flanker accuracy, and the Flanker interference effect remained statistically invariant across testing waves in both athletic age cohorts ($p > 0.05$). This stability suggests that competitive seasonal adaptations are not uniformly distributed across all

executive domains. The resilience of the interference effect suggests that baseline inhibitory control networks may remain relatively stable across a single competitive cycle in this age bracket. Collectively, these age-specific findings suggest that seasonal changes were not uniform across cognitive domains; however, because of the small control subgroups and the absence of direct age-specific group-by-time comparisons, these patterns should be interpreted descriptively rather than as evidence of basketball-specific cognitive enhancement.

The U16 cohort showed a relatively stable within-season cognitive profile, with no statistically significant overall time effects across the assessed outcomes. These findings should be interpreted cautiously because no age-comparable U16 control group was available and the subgroup was relatively small. Although U16 players displayed relatively high Flanker accuracy and fast reaction times at baseline, the data do not provide sufficient evidence to establish a generalized ceiling effect or a developmental plateau. Indeed, CDT response time numerically increased across the season, while CDT accuracy showed only a non-significant trend toward change. It is therefore possible that domain-general computerized tasks are less sensitive to subtle expertise-related changes in older and more experienced athletes, but this interpretation remains tentative. Future studies using larger age-comparable samples and more ecologically valid sport-specific tasks are needed to characterize cognitive trajectories at this developmental stage [32,48].

In summary, the present findings indicate that cognitive performance changed in a domain-specific manner across the competitive season. The CDT findings reflected differences in the timing and shape of the seasonal trajectories, with controls improving earlier and basketball players later in the season, rather than a persistent separation between groups. Timewall improvement was evident within basketball players without a significant group-by-time interaction, whereas Flanker reaction-time changes occurred in parallel across both groups. These patterns do not establish a direct causal effect of basketball training and should be interpreted considering repeated testing, developmental change, baseline differences, and the observational design. The exploratory U16 findings were comparatively stable but cannot be interpreted as evidence of a developmental plateau because an age-comparable control group was not available. Future longitudinal studies should combine larger control samples with sport-specific and ecologically valid cognitive assessments.

The domain-general computerized tasks used in this study should also be interpreted in light of their ecological limitations. Although they allow selected cognitive processes to be assessed under standardized conditions, they do not reproduce the simultaneous processing of teammates, opponents, ball trajectories, physical exertion, and time pressure involved in basketball-specific tactical decision-making. Therefore, any basketball-related change in these domain-general tasks would represent far transfer, which cannot be established by the present observational design; changes in PEBL performance should not be assumed to translate directly into on-court decision-making [28].

Limitations

While the three-wave longitudinal design and strictly standardized testing protocols represent notable strengths of this study, several methodological limitations should be acknowledged. First, although the overall sample comprised 91 basketball players and 30 non-athlete controls, recruitment of non-athlete controls was more challenging because, unlike the basketball players who were followed within organized team settings, potential controls were not affiliated with a regular training environment that facilitated repeated seasonal participation. This resulted in a relatively small U12 control subgroup. In addition, an age-comparable U16 control group could not be included because the available participants in this age range were preparing for university entrance examinations during

the data-collection period, and participation was therefore not pursued to avoid additional academic burden. Consequently, the primary athlete-control analyses were restricted to the combined U12+U14 cohort, whereas the U16 analyses were treated as exploratory and athlete-only. In addition, outcome-specific complete-case analyses reduced the effective longitudinal sample size for some measures and may have limited statistical power or introduced attrition-related bias. This reduction was most pronounced for the Flanker interference effect, for which the complete-case analysis included 38 basketball players and 22 controls; consequently, the precision and statistical power of this analysis were particularly limited, and its null findings should be interpreted cautiously. Although minimum weekly training frequency and typical match exposure were documented, individual training load, match minutes, recovery status, and mental fatigue were not systematically quantified; therefore, their potential contribution to longitudinal cognitive variation cannot be excluded [30]. Second, menstrual cycle phase was not monitored among female participants; therefore, possible short-term hormonal influences on cognitive performance could not be examined directly. Biological maturation was not directly assessed using measures such as pubertal staging or peak height velocity; therefore, residual developmental differences between participants cannot be completely excluded, even though age and sex were accounted for in the primary longitudinal analyses. Finally, the domain-general computerized tasks used in this study provided standardized measures of cognitive performance but cannot fully reproduce the stereoscopic visual tracking, physical fatigue, time pressure, and complex tactical decision-making encountered during competitive basketball. Repeated exposure to the same computerized tasks may also have contributed to changes across assessment waves. Although the repeatedly tested control group and standardized familiarization procedures provide some context for this possibility, practice effects cannot be completely separated from developmental or training-related changes [44].

5. Conclusions

The present study indicates that cognitive changes across a competitive basketball season are domain-specific rather than uniform across cognitive functions. Small athlete-control differences were observed in the seasonal pattern of change-detection performance. Basketball players also demonstrated marked within-season improvements in temporal anticipation, although the corresponding time-by-group interaction did not reach statistical significance. In contrast, Flanker reaction time improved in both athletes and non-athlete controls, suggesting that changes in general processing speed were not specific to basketball participation. Exploratory analyses in U16 players showed no significant overall seasonal time effects, although the absence of an age-comparable control group limits interpretation at this developmental stage. Given the observational design, the present findings should not be interpreted as evidence of a direct causal effect of basketball training. Future studies should combine larger age-comparable control samples, measures of biological maturation and training exposure, and sport-specific cognitive assessments incorporating dynamic visual information, physical exertion, and tactical decision-making.

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Abbreviations

The following abbreviations are used in this manuscript:

ANOVA	Analysis of variance
CDT	Change Detection Test
PEBL	Psychology Experiment Building Language
RT	Reaction time
U12	Under-12 competitive age category
U14	Under-14 competitive age category
U16	Under-16 competitive age category

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