Vol. 11, No. 1, 2026, pp. 122-132
DOI: https://doi.org/10.29210/30036835000

Contents lists available at Journal ELORA

JRTI (Jurnal Riset Tindakan Indonesia)
ISSN: 2502-079X (Print) ISSN: 2503-1619 (Electronic)

Journal homepage: https://jrti.eloracenter.org/jrti

Neurocognitive training versus conventional drills for reactive agility in tennis players

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Article Info

Article history:

Received May 26th, 2026
Revised Jun 1st, 2026
Accepted Jun 12th, 2026

Keywords:

Neurocognitive training
Reactive agility
Decision-making
Cognitive-motor training
Racket sports

ABSTRACT

Traditional agility training in tennis primarily emphasizes pre-planned movement patterns and may not adequately address the perceptual-cognitive demands required during competitive play. Neurocognitive training has emerged as a promising approach that integrates cognitive processing, visual perception, decision-making, and motor execution simultaneously. Therefore, this study aimed to compare the effects of neurocognitive training and conventional agility drills on reactive agility and match performance in competitive tennis players. This study employed a randomized controlled experimental design involving 30 competitive tennis players aged 18–24 years. Participants were randomly assigned to either the Neurocognitive Training Group (NTG; n = 15) or the Conventional Drill Group (CDG; n = 15). Both groups completed an 8-week intervention program conducted three times weekly. Reactive agility, reaction time, decision-making accuracy, and tennis match-performance indicators were assessed before and after the intervention using stimulus-based agility testing, computerized cognitive assessments, and standardized match analysis. Data were analyzed using repeated-measures ANOVA with a significance level of $p < 0.05$. The results demonstrated significant improvements in both groups; however, the NTG showed greater enhancement across all variables. Reactive agility improved by 13.52% in the NTG compared with 6.45% in the CDG ($p < 0.001$). Decision-making accuracy increased from 74.18% to 86.53% in the NTG, while the CDG improved from 75.01% to 79.42%. Additionally, rally success percentage increased significantly in the NTG (51.27% to 63.82%) compared with the CDG (50.94% to 56.17%). In conclusion, neurocognitive training was more effective than conventional drills in improving reactive agility, cognitive responsiveness, and match performance in tennis players.

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Introduction

The importance of neurocognitive training becomes increasingly evident when considering how modern tennis has evolved into a highly dynamic sport characterized by rapid rallies, multidirectional movement patterns, and continuous perceptual decision-making under time pressure. Success in contemporary tennis is no longer determined solely by technical proficiency or physical conditioning, but also by the athlete's ability to rapidly process visual information, anticipate opponents' actions, and execute efficient motor responses within fractions of a second.. Success in contemporary tennis is no longer determined solely by technical proficiency or physical conditioning, but also by the athlete's ability to rapidly process visual information, anticipate opponents' actions, and execute efficient motor responses within fractions of a second. Among the performance variables that have received increasing attention in recent years, reactive agility has emerged as one of the most important determinants of competitive tennis success. Reactive agility refers to the ability to rapidly change body position or direction in response to an external stimulus, integrating perceptual, cognitive, and motor components simultaneously. Unlike pre-planned agility, reactive agility requires athletes to perceive environmental cues, interpret relevant information, make immediate decisions, and execute movement responses accurately and efficiently during unpredictable situations. In tennis, this ability becomes essential because players constantly respond to ball trajectories, opponent positioning, stroke variations, and tactical patterns in real time.

Reactive agility has been widely assessed using stimulus-based testing protocols that combine perceptual processing and rapid directional movement responses. Previous studies have demonstrated strong reliability of reactive agility assessments in open-skill sports, with reported test–retest intraclass correlation coefficients (ICC) ranging from 0.81 to 0.92 and coefficients of variation below 5%. Furthermore, research comparing elite and sub-elite athletes has shown moderate-to-large performance differences in reactive agility outcomes (Cohen's d = 0.65–1.20), indicating that perceptual-cognitive processing contributes substantially to competitive performance. These findings support the use of stimulus-driven reactive agility measures as valid indicators of sport-specific responsiveness and provide an empirical basis for evaluating training-induced adaptations in tennis athletes.

Studies on perceptual-cognitive expertise in racket sports have consistently demonstrated that elite performers possess superior anticipation skills, faster decision-making speed, and more efficient visual search strategies than novice athletes. For example, (Buszard 2022; Keller et al., 2023; Starzak et al., 2024) reported that skilled racket-sport athletes exhibit enhanced anticipatory abilities and more accurate movement predictions under time-constrained conditions. Similarly, (Zhu et al.v2024;Silva et al., 2021; Wang et al., 2025; Zhu et al., 2024), in a systematic review and meta-analysis, concluded that perceptual-cognitive training significantly improves anticipation and decision-making performance across competitive sport settings. Recent tennis-specific evidence further suggests that visuospatial working memory and visual information-processing efficiency are strongly associated with tactical decision-making quality among advanced tennis players (Yufei & Ningning, 2026). These findings collectively indicate that high-level tennis performance depends not only on physical capabilities but also on advanced perceptual-cognitive functioning.

Reactive agility deficits may negatively affect multiple aspects of tennis performance. Athletes with delayed perceptual processing often struggle with court coverage, shot preparation timing, and tactical responsiveness during fast-paced rallies. In competitive matches, even minimal delays in reaction time may increase the likelihood of unforced errors, ineffective shot selection, and poor defensive positioning. Furthermore, prolonged cognitive demands during intense matches can induce mental fatigue, which subsequently reduces attentional efficiency and decision-making quality. Previous research has shown that mental fatigue negatively affects executive functioning, attentional control, and sport-specific decision-making performance, particularly in open-skill sports requiring continuous information processing under time pressure. As cognitive fatigue accumulates, athletes may experience slower reaction times, impaired anticipation, and reduced tactical effectiveness during competition. The interaction between cognitive fatigue and motor execution is particularly important in tennis because athletes must sustain rapid information processing throughout extended match durations. Inadequate reactive agility may therefore contribute not only to decreased match performance but also to increased injury risk due to delayed neuromuscular responses during high-speed directional changes.

Traditionally, tennis conditioning programs have emphasized conventional agility drills such as cone drills, ladder exercises, shuttle runs, and multidirectional sprint training. These methods primarily focus on improving physical movement efficiency, acceleration, deceleration, and change-of-direction speed. Although conventional drills remain effective for enhancing fundamental athletic qualities, they are often performed in predictable and pre-planned environments that lack the perceptual and decision-making demands present during actual competition. As a result, researchers and practitioners have increasingly questioned whether traditional agility training alone adequately prepares athletes for the complex cognitive-motor challenges encountered during competitive tennis matches.

In response to these limitations, neurocognitive training has emerged as a promising approach for enhancing sport-specific performance. Neurocognitive training refers to training methods that simultaneously target cognitive processes and motor execution through integrated perceptual-motor tasks. These interventions commonly include visual reaction drills, dual-task exercises, anticipation training, stroboscopic vision training, and decision-making simulations designed to improve the interaction between the brain and the musculoskeletal system. The theoretical foundation of neurocognitive training is strongly linked to perception-action coupling theory, which proposes that effective athletic performance depends on the continuous interaction between sensory information and motor behavior. Additionally, ecological dynamics theory suggests that athletes adapt their movement behavior according to environmental constraints, requiring continuous perceptual recalibration during sport participation. Therefore, training programs that integrate cognitive and physical components may produce greater transfer to competitive performance than isolated physical training approaches.

Recent studies in open-skill sports have demonstrated the potential effectiveness of cognitive-motor interventions for improving agility, reaction time, and decision-making performance. Research involving elite basketball athletes showed that cognitive-motor dual-task training integrated within agility-focused conditioning significantly improved both sprint performance and decision-making speed compared with motor training alone. Similarly, studies investigating visuomotor complexity in reactive agility training have suggested that cognitively demanding tasks may enhance perceptual-processing efficiency and responsiveness to unpredictable stimuli (Lucia, Digno, et al., 2023; Zhang et al., 2026; Zwierko et al., 2023). Within tennis specifically, emerging evidence indicates that combined cognitive and physical training may improve on-court responsiveness and tactical efficiency under high-pressure situations (Zhang et al., 2025). Moreover, research on tennis players' visual search behavior and visuospatial working memory has highlighted the critical role of cognitive processing in anticipatory tactical decision-making (Icemet & Zhang, 2026; Yufei & Ningning, 2026; Zhang et al., 2026; Zwierko et al., 2023)

Despite these advances, several important research gaps remain unresolved. First, relatively few studies have directly compared neurocognitive training with conventional agility drills within the context of tennis performance. Existing literature has largely focused either on isolated cognitive interventions or traditional physical conditioning methods without examining their comparative effectiveness. Second, many previous studies have methodological limitations, including small sample sizes, short intervention durations, and insufficient measurement of actual match-performance outcomes. Third, most existing investigations emphasize laboratory-based cognitive assessments rather than integrating practical match-performance indicators such as rally success, unforced errors, and tactical efficiency during real gameplay situations. Consequently, the practical superiority of neurocognitive training over conventional drills in tennis remains unclear (Xiao et al., 2024, 2025).

Another limitation in current literature is the insufficient integration of cognitive and motor performance variables within a unified training framework. Tennis is fundamentally an open-skill sport requiring simultaneous perception, anticipation, movement adaptation, and technical execution under rapidly changing environmental conditions. Therefore, training models that fail to replicate these sport-specific cognitive demands may produce limited transferability to actual competition. Neurocognitive training may provide a more ecologically valid training stimulus because it integrates visual processing, reaction speed, attentional control, and motor execution into a single training environment that resembles competitive match situations more closely than conventional drills (Renshaw et al., 2019; Yang et al., 2026).

From a practical perspective, identifying the most effective training approach for improving reactive agility has substantial implications for coaches, sport scientists, and conditioning professionals. Evidence-based conditioning strategies are essential for optimizing athlete development, improving competitive performance, and reducing performance limitations associated with delayed decision-making or inefficient movement responses. If neurocognitive training demonstrates superior effectiveness compared with traditional drills, coaches may need to reconsider current conditioning practices and incorporate more cognitively demanding exercises into routine tennis training programs (Huang et al., 2020; Ünver et al., 2023; Walker et al., 2021).

Therefore, the purpose of this study is to compare the effects of neurocognitive training and conventional drills on reactive agility and match performance in tennis players. Specifically, this research aims to evaluate changes in reactive agility, reaction time, and match-performance indicators following structured intervention programs. The study also seeks to determine whether neurocognitive training produces greater improvements in tennis-specific performance outcomes compared with conventional agility drills. It is hypothesized that athletes participating in neurocognitive training will demonstrate significantly greater improvements in reactive agility and match performance due to enhanced perceptual-cognitive processing and more efficient perception-action integration.

Method

Research Design

This study employed a randomized controlled experimental design using a pretest–posttest comparative approach to examine the effects of neurocognitive training and conventional agility drills on reactive agility and match performance in tennis players. The design was selected to determine causal relationships between the training interventions and performance outcomes while minimizing potential confounding variables.

Participants were randomly assigned into two intervention groups: the Neurocognitive Training Group (NTG) and the Conventional Drill Group (CDG). Both groups completed identical baseline and post-intervention assessments before and after the intervention period.

The intervention program lasted eight weeks with a training frequency of three sessions per week in addition to the athletes' regular tennis practice schedules. Each intervention session lasted approximately 45–60 minutes. Both groups received equal total training volume and intensity to ensure that differences in outcomes were attributable to the nature of the intervention rather than discrepancies in workload. The study design followed recommendations for sport-performance intervention research emphasizing ecological validity and sport-specific training application.

Participants

The participants consisted of 30 competitive tennis players recruited from regional tennis academies and university-level tennis clubs. Athletes were selected using purposive sampling based on predefined inclusion criteria relevant to competitive tennis performance. The participants included male and female athletes aged between 18 and 24 years who had a minimum of three years of competitive tennis experience and were actively participating in regional or national tournaments during the study period. Participants were eligible for inclusion if they met the following criteria: (1) actively engaged in structured tennis training at least four times per week, (2) free from musculoskeletal injury during the previous six months, (3) no diagnosed neurological or visual disorders, and (4) willingness to complete all intervention and testing sessions. Athletes were excluded if they had recent lower-limb injuries, chronic balance disorders, cardiovascular limitations, or inconsistent training attendance exceeding 15% of the intervention sessions.

An a priori power analysis was conducted using G*Power software (version 3.1) for repeated-measures ANOVA with two groups and two measurement occasions. Assuming a moderate effect size ($f = 0.25$), $\alpha = 0.05$, and statistical power of 0.80, the minimum required sample size was estimated at 28 participants. Therefore, the inclusion of 30 athletes was considered sufficient to detect meaningful intervention effects. Before data collection, all participants received a detailed explanation regarding the purpose, procedures, benefits, and potential risks of the study. Written informed consent was obtained from all participants prior to participation. Ethical approval for the study was granted by the Institutional Research Ethics Committee in accordance with the Declaration of Helsinki for human subject research.

Instruments and Measurements

Reactive Agility Assessment

Reactive agility was assessed using a stimulus-based Reactive Agility Test (RAT). The testing protocol required participants to respond to randomized visual stimuli generated through a light-based reaction system positioned around the testing area. Athletes were instructed to move as quickly as possible toward the illuminated target while maintaining correct movement mechanics and body control. Total completion time and reaction time were recorded electronically using timing sensors with millisecond precision.

The RAT protocol was selected because it integrates perceptual processing and movement execution, making it more representative of sport-specific reactive agility demands than pre-planned change-of-direction tests. Previous studies have demonstrated acceptable reliability and validity of reactive agility assessments in open-skill sports environments. The Reactive Agility Test (RAT) employed in this study was selected based on previous evidence demonstrating acceptable reliability and validity in open-skill sports. Earlier investigations reported test–retest reliability values ranging from ICC = 0.84 to 0.91 and measurement error below 5%, supporting its suitability for evaluating perceptual-motor responsiveness under unpredictable stimulus conditions.

Match Performance Assessment

Match performance was evaluated using standardized tennis match analysis procedures conducted during simulated competitive matches. Each participant played two supervised matches before and after the intervention period under standardized court and environmental conditions. Match statistics were recorded using video analysis software and observational coding procedures. The primary match-performance indicators included: number of winners, number of unforced errors, successful return percentage, rally success percentage, effective defensive recoveries and point-winning efficiency. Two independent tennis performance analysts reviewed all match recordings to ensure scoring reliability and reduce observer bias. Inter-rater reliability was calculated prior to data analysis.

Neurocognitive Performance Assessment

Neurocognitive performance was measured using computerized reaction-time and decision-making assessments. Simple reaction time, choice reaction time, and visuomotor response speed were evaluated using a

computerized cognitive testing platform. Participants completed standardized visual recognition and response tasks requiring rapid motor reactions to randomized stimuli presented on a digital display.
Decision-making performance was additionally evaluated using tennis-specific video-based anticipation tests in which athletes predicted ball direction and tactical outcomes based on opponent movement patterns. The tests aimed to assess perceptual anticipation and information-processing efficiency relevant to tennis performance.

Anthropometric Measurements

Basic anthropometric variables including height, body mass, age, and training experience were collected before the intervention. Height was measured using a stadiometer to the nearest 0.1 cm, while body mass was measured using a calibrated digital scale to the nearest 0.1 kg.

Research Procedures

Familiarization Session

Prior to baseline testing, all participants attended a familiarization session designed to reduce learning effects during data collection. During this session, participants practiced the reactive agility tests, cognitive assessments, and movement protocols under supervision. Standardized instructions were provided to ensure consistency across participants.

Pre-Intervention Testing

Baseline assessments were conducted one week before the intervention period. Participants completed anthropometric measurements, reactive agility testing, neurocognitive assessments, and simulated match-performance evaluations. Testing sessions were conducted at the same time of day to minimize circadian influences on performance outcomes. Participants were instructed to avoid intense physical activity, caffeine, and sleep deprivation for at least 24 hours before testing. Standardized warm-up protocols consisting of dynamic stretching, mobility exercises, and light multidirectional movement drills were completed before each testing session.

Intervention Programs

Neurocognitive Training Group

Participants assigned to the Neurocognitive Training Group completed a sport-specific neurocognitive training program designed to simultaneously stimulate cognitive processing and motor execution. Training sessions included: (1) Visual reaction drills using randomized light stimuli; (2) Dual-task movement exercises combining cognitive tasks with multidirectional footwork; (3) Anticipation-based tennis drills involving opponent cue recognition; (4) Peripheral vision and attentional-focus exercises; (5) Decision-making tasks integrated with tennis movement patterns; (6) Reactive sprint and recovery drills under unpredictable stimulus conditions. The complexity and intensity of the neurocognitive tasks progressively increased throughout the intervention period. Coaches provided immediate feedback to enhance movement efficiency and perceptual responsiveness.

Conventional Drill Group

Participants in the Conventional Drill Group completed traditional tennis agility and conditioning drills emphasizing physical movement patterns without additional cognitive stimulus integration. The training program included: (1) Cone-based change-of-direction drills; (2) Agility ladder exercises; (3) Shuttle runs; (4) Multidirectional sprint training; (5) Footwork repetition drills; (6) Linear acceleration and deceleration exercises. The conventional drills were structured to match the duration and physical intensity of the neurocognitive intervention while maintaining standardized training loads between groups.

Training Standardization and Bias Control

To ensure intervention consistency, all training sessions were supervised by certified tennis conditioning coaches trained in the study protocols. Training intensity was monitored using session rating of perceived exertion (sRPE) scales and heart-rate monitoring. Equal rest intervals and workload progression were maintained across groups. Several strategies were implemented to minimize bias, including: (1) Random allocation of participants; (2) Standardized testing instructions; (3) Familiarization sessions before data collection; (4) Blinded performance analysts during match analysis; (5) Consistent environmental and testing conditions. 111111Attendance was recorded for all sessions, and participants completing less than 85% of the training sessions were excluded from final analysis.

Data Analysis

Descriptive statistics including means, standard deviations, percentages, and confidence intervals were calculated for all variables. Data normality was evaluated using the Shapiro–Wilk test, while homogeneity of variance was assessed using Levene’s test.

Inferential statistical analysis was conducted using repeated-measures analysis of variance (ANOVA) to examine within-group and between-group differences over time. When significant interaction effects were identified, Bonferroni post hoc analysis was applied to determine pairwise differences between groups. Effect sizes were calculated using partial eta squared (η^2) and Cohen's d to determine the magnitude of intervention effects. Statistical significance was established at $p < 0.05$. All analyses were performed using IBM SPSS Statistics software version 27.0.

The statistical approach was selected to comprehensively evaluate both the effectiveness of each intervention and the comparative differences between neurocognitive training and conventional agility drills on reactive agility and tennis match performance outcomes.

Results and Discussions

Participant Characteristics

A total of 30 competitive tennis players completed the intervention program and were included in the final analysis. No participant withdrew during the study period, and training attendance exceeded 90% in both groups. Baseline demographic and anthropometric characteristics demonstrated no statistically significant differences between the Neurocognitive Training Group (NTG) and the Conventional Drill Group (CDG), indicating that the groups were homogeneous prior to the intervention.

Table 1. Baseline Characteristics of Participants

Variable	NTG (n = 15) Mean ± SD	CDG (n = 15) Mean ± SD	p-value
Age (years)	20.47 ± 1.68	20.13 ± 1.72	0.612
Height (cm)	174.26 ± 6.14	173.81 ± 5.97	0.847
Body Mass (kg)	68.42 ± 7.11	67.95 ± 6.88	0.791
Training Experience (years)	5.93 ± 1.27	5.71 ± 1.33	0.684
Weekly Training Frequency (sessions/week)	5.12 ± 0.74	5.08 ± 0.69	0.903

The findings presented in Table 1 indicate that both groups possessed similar demographic and training characteristics before the intervention. This baseline equivalence supports the validity of subsequent comparisons between intervention outcomes.

Normality and Homogeneity Testing

Prior to inferential analysis, assumptions of normality and homogeneity were examined to determine the suitability of parametric statistical procedures.

Table 2. Results of Normality and Homogeneity Tests

Variable	Shapiro–Wilk p-value	Levene's Test p-value	Interpretation
Reactive Agility Time	0.214	0.371	Normal and Homogeneous
Reaction Time	0.176	0.428	Normal and Homogeneous
Rally Success Percentage	0.293	0.517	Normal and Homogeneous
Unforced Errors	0.185	0.463	Normal and Homogeneous
Winners	0.247	0.401	Normal and Homogeneous

The Shapiro–Wilk test results demonstrated that all variables were normally distributed ($p > 0.05$), while Levene's test indicated homogeneity of variance between groups ($p > 0.05$). Therefore, repeated-measures ANOVA was considered appropriate for subsequent statistical analysis.

Reactive Agility Performance

Reactive agility performance improved significantly in both groups following the intervention period. However, the Neurocognitive Training Group demonstrated greater improvements compared with the Conventional Drill Group.

Table 3. Reactive Agility Performance Before and After Intervention

Group	Pretest (s) Mean ± SD	Posttest (s) Mean ± SD	Improvement (%)	p-value
NTG	2.81 ± 0.19	2.43 ± 0.16	13.52%	<0.001
CDG	2.79 ± 0.21	2.61 ± 0.18	6.45%	0.012

The results in Table 3 indicate that both interventions significantly enhanced reactive agility performance. Nevertheless, the NTG exhibited nearly double the percentage improvement observed in the CDG. The between-group analysis revealed a statistically significant interaction effect favoring neurocognitive training ($p < 0.01$).

Neurocognitive Performance Outcomes

The neurocognitive assessments demonstrated significant reductions in reaction time and improvements in decision-making speed following neurocognitive training.

Table 4. Neurocognitive Performance Outcomes

Variable	Group	Pretest Mean ± SD	Posttest Mean ± SD	p-value
Simple Reaction Time (ms)	NTG	312.47 ± 18.22	271.13 ± 16.45	<0.001
	CDG	309.86 ± 17.95	295.71 ± 18.10	0.041
Choice Reaction Time (ms)	NTG	487.22 ± 25.63	431.08 ± 21.37	<0.001
	CDG	483.95 ± 24.48	466.31 ± 23.17	0.048
Decision-Making Accuracy (%)	NTG	74.18 ± 5.62	86.53 ± 4.91	<0.001
	CDG	75.01 ± 5.34	79.42 ± 5.11	0.039

Table 4 demonstrates that the Neurocognitive Training Group experienced substantially greater improvements in cognitive-processing variables compared with the Conventional Drill Group. The most pronounced improvement was observed in decision-making accuracy, suggesting enhanced perceptual-cognitive efficiency following the neurocognitive intervention.

Match Performance Outcomes

Significant improvements in match-performance indicators were observed following both intervention programs. However, athletes in the Neurocognitive Training Group demonstrated superior competitive performance enhancement.

Table 5. Match Performance Indicators Before and After Intervention

Variable	Group	Pretest Mean ± SD	Posttest Mean ± SD	p-value
Winners (points/match)	NTG	18.27 ± 3.44	24.86 ± 3.18	<0.001
	CDG	18.01 ± 3.17	20.75 ± 3.09	0.036
Unforced Errors (points/match)	NTG	16.42 ± 2.71	11.38 ± 2.16	<0.001
	CDG	16.08 ± 2.53	14.67 ± 2.31	0.049
Rally Success (%)	NTG	51.27 ± 4.11	63.82 ± 4.56	<0.001
	CDG	50.94 ± 4.32	56.17 ± 4.07	0.028
Successful Returns (%)	NTG	68.13 ± 5.07	78.94 ± 4.62	<0.001
	CDG	67.88 ± 5.14	72.16 ± 4.89	0.044

The data presented in Table 5 indicate that neurocognitive training produced more substantial improvements in tactical and competitive match performance. Participants in the NTG achieved higher numbers of winners, improved rally success, and reduced unforced errors more effectively than athletes undergoing conventional drills.

Comparative Analysis Between Groups

To determine the comparative effectiveness of both interventions, repeated-measures ANOVA was conducted across all primary outcome variables.

Table 6. Between-Group Comparative Analysis

Variable	F-value	p-value	Partial η^2	Interpretation
Reactive Agility	11.84	<0.001	0.318	Large Effect
Simple Reaction Time	10.73	<0.001	0.294	Large Effect
Choice Reaction Time	12.16	<0.001	0.327	Large Effect
Rally Success Percentage	9.91	0.003	0.281	Moderate–Large Effect
Unforced Errors	8.47	0.006	0.247	Moderate Effect

The magnitude of intervention effects ranged from moderate to large across the primary outcome variables. Partial eta-squared values exceeded the conventional threshold for large effects ($\eta^2 > 0.14$) for reactive agility, reaction time, and decision-making outcomes, indicating that neurocognitive training produced practically meaningful improvements beyond statistical significance alone.

The comparative analysis revealed statistically significant differences between the intervention groups across all major variables. Neurocognitive training consistently demonstrated larger effect sizes than conventional drills, particularly in reactive agility and neurocognitive performance measures. Overall, the results suggest that integrating cognitive-perceptual components into tennis conditioning programs may provide superior improvements in both reactive agility and match-related performance compared with traditional agility-focused training alone.

The present study aimed to compare the effects of neurocognitive training and conventional agility drills on reactive agility and match performance in competitive tennis players. The findings demonstrated that both intervention models improved athletic performance variables; however, neurocognitive training produced significantly greater improvements in reactive agility, reaction time, decision-making accuracy, and match-performance indicators compared with conventional drills. These findings support previous evidence indicating that training programs integrating perceptual-cognitive stimulation with motor execution may provide greater sport-specific adaptation than traditional physical conditioning approaches alone. Recent research in open-skill sports has shown that neurocognitive interventions improve both cognitive processing speed and reactive movement performance under unpredictable competitive conditions (Jiang et al., 2025; Li et al., 2026; Lucia, Bianco, et al., 2023; Shih et al., 2025)

One of the most important findings of this study was the substantial improvement in reactive agility observed in the Neurocognitive Training Group (NTG). Although the Conventional Drill Group (CDG) also demonstrated significant improvements, the magnitude of enhancement was considerably greater in the NTG. This finding suggests that reactive agility in tennis is strongly influenced not only by physical movement capabilities but also by perceptual and decision-making processes. According to (Horička & Hianik, 2016; Mackala et al., 2020; Popowczak et al., 2021), reactive agility differs fundamentally from pre-planned change-of-direction speed because it requires athletes to perceive environmental stimuli, process information rapidly, and generate immediate movement responses. In tennis, where players continuously react to ball trajectories, opponent positioning, and tactical variations, cognitive responsiveness becomes a critical component of successful movement execution.

The superior reactive agility adaptations observed following neurocognitive training can be explained through the theory of perception-action coupling. This framework proposes that movement behavior emerges through continuous interaction between sensory information and motor execution. Neurocognitive training drills involving randomized visual stimuli, anticipation tasks, and dual-task movement exercises likely enhanced athletes' ability to integrate visual perception with motor responses more efficiently. Similar findings were reported by (Büchel et al., 2022), who demonstrated that cognitively demanding agility exercises improved reactive movement efficiency more effectively than traditional agility drills among elite athletes.

The findings are also consistent with ecological dynamics theory, which emphasizes that athletic performance is shaped by adaptive interactions between athletes and changing environmental constraints. Tennis players rarely perform movements under predictable conditions during actual matches. Instead, they continuously adapt to rapidly changing stimuli. Neurocognitive training may therefore provide greater ecological validity because the training environment more closely resembles real competitive situations. Research by (Russo et al., 2022; Schumacher et al., 2020; Triggs et al., 2025; Wu et al., 2025, 2025) demonstrated that perceptual-cognitive training improves athletes' adaptability during open-skill sports by enhancing attentional flexibility and sensorimotor responsiveness.

Another significant finding in this study was the marked reduction in reaction time and improvement in decision-making accuracy among athletes in the NTG. These improvements indicate that neurocognitive training enhanced both neural processing speed and perceptual efficiency. Tennis performance relies heavily on rapid information processing because athletes have only limited time to identify environmental cues and execute tactical responses. According to (Buszard, 2022), elite racket-sport athletes possess superior anticipatory skills and faster visuomotor processing than lower-level performers, allowing them to respond more effectively under time pressure.

The improvement in cognitive-related variables may also be associated with enhanced attentional control and visuospatial processing developed during the intervention. Neurocognitive exercises such as visual tracking tasks, peripheral awareness drills, and dual-task movement challenges stimulate executive functioning and neural coordination between sensory and motor systems. Previous evidence suggests that repeated exposure to cognitively demanding movement tasks promotes neuroplastic adaptation and improves neural efficiency during sport-specific activities (Ben Ezzdine et al., 2025). This may explain why athletes in the NTG demonstrated faster simple and choice reaction times after the intervention period.

Importantly, the improvements observed in neurocognitive performance translated into meaningful enhancements in actual tennis match outcomes. Athletes in the NTG achieved significantly greater increases in winners, rally success percentage, and successful returns while simultaneously reducing unforced errors more effectively than athletes in the CDG. These findings indicate that neurocognitive training has practical transferability to competitive performance rather than merely improving isolated laboratory-based outcomes. Similar results were reported by (Zhu et al., 2024), who found that perceptual-cognitive training improved tactical efficiency and on-court decision-making in elite racket-sport athletes.

The reduction in unforced errors observed in the NTG is particularly important because unforced errors are often associated with delayed perception, poor anticipation, and inadequate positioning during rallies. Improved perceptual-cognitive processing likely allowed athletes to prepare earlier and execute strokes with greater technical stability under pressure. Furthermore, the increase in rally success percentage suggests improved tactical consistency and movement efficiency during prolonged exchanges. Athletes with superior perceptual-cognitive abilities demonstrate more efficient visual search behavior and better anticipation of opponent actions, which contributes directly to improved match performance.

The present findings are consistent with earlier research involving neurocognitive and dual-task training interventions in open-skill sports. Studies in soccer, basketball, and badminton have reported that integrating cognitive stimuli into agility training produces greater improvements in reactive performance than conventional movement drills alone (Komari et al., 2026). However, the current study extends previous literature by specifically examining tennis athletes while simultaneously evaluating both cognitive and match-performance outcomes. This integrated approach provides stronger evidence regarding the practical effectiveness of neurocognitive training within tennis conditioning programs.

Despite these positive findings, several limitations should be acknowledged. First, the sample size was relatively small, which may limit generalizability to larger tennis populations. Although statistically significant differences were observed, future studies involving larger and more diverse participant samples are necessary to confirm the consistency of these findings. Second, the intervention duration was limited to eight weeks. Longer-term interventions may provide greater insight into the sustainability of cognitive and reactive agility adaptations over time.

Another limitation is the absence of direct neurophysiological measurements such as electroencephalography (EEG), eye-tracking analysis, or functional brain imaging. While improvements in reaction time and decision-making suggest enhanced neural efficiency, the precise neurobiological mechanisms underlying these adaptations could not be directly evaluated. Future investigations should therefore incorporate neurophysiological assessments to better understand how neurocognitive training influences brain activation and perceptual processing in tennis athletes.

In practical application, the findings suggest that coaches and conditioning specialists should consider integrating perceptual-cognitive components into tennis training programs. Conventional drills remain important for developing foundational movement skills and physical conditioning; however, combining physical exercises with cognitive challenges may produce greater transfer to actual competition. Neurocognitive training methods such as reactive light systems, anticipation exercises, and decision-making drills may help athletes improve not only movement efficiency but also tactical responsiveness during high-pressure match situations.

Overall, the present study demonstrates that neurocognitive training provides superior improvements in reactive agility, cognitive responsiveness, and match performance compared with conventional drills in tennis players. These findings reinforce the importance of integrating cognitive-perceptual training into modern tennis conditioning programs and support the growing recognition that successful athletic performance depends on the interaction between cognitive and physical capabilities.

Conclusions

This study investigated the comparative effects of neurocognitive training and conventional agility drills on reactive agility and match performance in competitive tennis players. The findings demonstrated that both training approaches contributed to improvements in physical and performance-related variables; however, neurocognitive training produced significantly greater enhancements in reactive agility, reaction time, decision-making accuracy, and overall match performance. Athletes who participated in neurocognitive training showed superior improvements in rally success percentage, successful returns, and reduction of unforced errors compared with those who completed conventional agility drills. The results indicate that reactive agility in tennis is strongly influenced by perceptual-cognitive processes in addition to physical movement capacity. Training programs that integrate visual processing, anticipation, attentional control, and rapid decision-making appear to provide greater transfer to actual competitive performance than traditional pre-planned movement drills. These findings support the growing evidence that modern tennis performance depends on the interaction between cognitive and motor abilities under unpredictable match conditions.

From a practical perspective, the study highlights the importance of incorporating neurocognitive components into tennis conditioning programs. Coaches and strength-conditioning professionals may benefit from integrating sport-specific cognitive challenges such as reactive visual stimuli, dual-task exercises, and decision-making drills into regular training sessions to optimize athlete performance. Despite several limitations, including sample size and intervention duration, the present study provides meaningful evidence supporting the effectiveness of neurocognitive training in tennis. Future research should explore longer intervention periods, larger athlete populations, and neurophysiological mechanisms underlying cognitive-motor adaptations in competitive sports.

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