

Anticipation performance and perceptual-cognitive training effect on anticipation skills in tennis serve return across youth age groups: A pilot exploratory study

-  **Jan Carboch**  . Faculty of Physical Education and Sport. Charles University. Prague, Czech Republic.
Kristina Mrazova. Faculty of Physical Education and Sport. Charles University. Prague, Czech Republic.
 **Vendula Redlichova**. Faculty of Physical Education and Sport. Charles University. Prague, Czech Republic.
 **Tomas Kocib**. Faculty of Physical Education and Sport. Charles University. Prague, Czech Republic.
 **John Brenton**. Accelerated Skill Acquisition. Perth, Australia.

ABSTRACT

While perceptual training can be effective in developing anticipation skills, it is not commonly incorporated into tennis practice sessions, especially for young players. This pilot exploratory intervention study aimed to assess the effect of perceptual-cognitive training based on video recordings of tennis serves modified by temporal occlusion on development of anticipatory skills in expert tennis players of various age categories, i.e. U12, U14, U18 and adults. A total of 19 participants were divided into intervention and control group based on the age. We used pre and post-test design with temporal occlusion design. The intervention group underwent a 3-week video-based perceptual-cognitive training program. Pre-tests results revealed that adults and U18 category reached better response rate compared to U14 and poor result of U12. After applying the perceptual-cognitive training, the results demonstrate its effect and improvement across all age categories. The U12 category showed considerable improvement, with both the U12 and U14 categories reaching the performance level of the U18 and adult participants in the post-test under the T4-T6 occlusion condition. Respecting the sample size, video-based perceptual training could be effective way to improve anticipation skills and performance even in young tennis players. However, further investigation in this area is needed to gain a deeper understanding.

Keywords: Performance analysis, Advance information, Temporal occlusion, Visual search, Perception, Decision-making.

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 **Corresponding author.** Charles University, Faculty of Physical Education and Sport, Department of Sport Games, Jose Martiho 31, Prague, Czech Republic.

E-mail: carby@post.cz

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INTRODUCTION

Players across different ages and skill levels develop varying degrees of perceptual and anticipatory abilities, which can significantly influence their overall performance in sport games (Abernethy & Zawi, 2007; Shim et al., 2006). In tennis and other fast-paced sports, the speed of the ball imposes strict time constraints on athletes' sensory perception and motor responses. Decisions must be made within milliseconds, with high accuracy, and under constantly changing temporal and spatial conditions (Müller et al., 2006). Perceptual-cognitive training can serve as a standard training method that provides athletes with repeated exposure to specific situations, both on the field and off it (e.g., when physical training is not possible due to injury or illness).

Perceptual-cognitive training involves using sport-specific visual information to make decisions, thereby enhancing performance through improved visual anticipation—predicting outcomes based on advance information, such as an opponent's movements (Broadbent et al., 2015). Beyond anticipation and decision-making, this training also develops additional perceptual-cognitive skills, including pattern recognition and the perception of contextual and situational information, which inform decision processes (Abernethy et al., 2005). During competition, athletes must extract relevant information while ignoring irrelevant details (Goldstone, 1998). Compared to novices, expert players can better detect and use both contextual and kinematic information to make accurate predictions (Abernethy & Zawi, 2007; Shim et al., 2006; Williams & Jackson, 2019). Contextual information may be visual (e.g., opponent positioning) or non-visual (e.g., score, wind) (Vernon et al., 2018). Kinematic information during a tennis serve includes movements of the server's body segments, the racket, or the ball toss. These cues appear before racket–ball contact, followed by key kinematic information from the initial ball-flight phase (Morris-Binelli et al., 2020).

Perceptual-cognitive training frequently uses video simulations of sport-specific situations, such as the tennis serve–return. After watching these videos, athletes are required to predict or decide the next event based on the observed visual information. The footage is typically filmed from the player's perspective and edited using temporal occlusion (Brenton et al., 2019). Temporal occlusion interrupts the video at predefined kinematic moments (e.g., during the server's motion or early ball flight), limiting access to visual information at critical points. Its purpose is to control the timing of available visual cues and determine when athletes extract information needed for anticipation (Williams et al., 2011).

The effectiveness of temporal-occlusion-based perceptual training on anticipation skills has been demonstrated in various sports games (Abernethy et al., 1999; Fadde, 2006; Murgia et al., 2014). Athletes undergoing visuomotor or visual-perception interventions were able to capture advance information and showed improved anticipation by identifying key details earlier in post-tests and transfer tests (Brenton et al., 2019). These findings indicate that players can benefit from video-based training and that the skills learned can transfer to real-game performance. Moreover, the research supports extensive evidence showing that experts are better than novices at extracting information from advance cues to make predictions.

Despite evidence that expert players use the opponent's early movement patterns, including the ball toss during the serve (Murray & Hunfalvy, 2017; Ward et al., 2002; Williams et al., 2002) to anticipate actions, there is a lack of research focusing on highly skilled younger athletes in temporally constrained situations such as the serve–return in tennis. Weissensteiner et al. (2008) has shown that athletes under 15 years old can extract advance information for prediction, yet there is limited evidence of how highly skilled younger athletes use such information in practice. Moreover, it remains unclear whether these abilities can be systematically enhanced through structured perceptual-cognitive training in junior expert populations.

Underdeveloped ability to detect and apply advance information from an opponent's movements may be a performance-limiting factor for younger players, highlighting the need to address this component of performance in training. Previous studies (Gabbett et al., 2007; Hopwood et al., 2011; Maman et al., 2011; Williams et al., 2003) have demonstrated the effectiveness of video-based perceptual training with temporal occlusion in enhancing anticipation skills, but they primarily included adult populations, leaving the developmental trajectory and trainability of junior experts (U12–U18) largely unexplored. Consequently, age-related differences in responsiveness to perceptual-cognitive training remain insufficiently examined. The aim is to assess the effect of perceptual-cognitive training based on video recordings of tennis serves modified by temporal occlusion on development of anticipatory skills in expert tennis players of various age categories, i.e. U12, U14, U18 and adults. Given the pilot nature of the study, it was expected that the intervention group would show greater pre–post improvements in anticipatory performance than the control group, with possible age-related differences.

MATERIAL AND METHODS

Participants

Nineteen participants (ten male and nine female) voluntarily agreed to take part in this experiment, based on convenience sampling. The study was designed as a pilot-controlled pre–post intervention. Participants were allocated to intervention (IG) and control (CG) groups using age-stratified assignment procedures to ensure a balanced distribution across age categories: U12, U14, U18, and adults. Both groups completed pre- and post-testing, while the intervention group additionally undertook a three-week perceptual-cognitive training program. The IG consisted of 3 U12 participants, 2 U14, 2 U18, and 2 adults. The CG included the same number of participants in each age category, except for the U12 group, which had 4 participants. The mean age of all participants was 16.5 ± 6.4 years, and they had been playing tennis for 10.4 ± 6.2 years. These participants had represented in international performance tennis or were national players playing in international tournaments. Their mean ranking in the national ranking of the Czech Republic in their age category was 33.0 ± 40.6 . An a priori power analysis using G*Power indicated that a total of 34 participants would be required to detect a medium effect ($f = .25$) for the group \times time interaction with $\alpha = .05$ and power = .80. The present sample of 19 participants therefore represents a pilot-level investigation. The Ethics Committee at the Faculty of Physical Education and Sport, at Charles University approved this study in accordance with the Declaration of Helsinki. All participants or their adult representatives were informed of the risks and benefits of the study and provided written informed consent prior to participating.

Methods and procedures

The pretest, perceptual training, and post-test involved watching edited video recordings of tennis serves from the perspective of the receiving player. Temporal occlusion was applied by prematurely ending the video recordings—blacking out the screen at predefined moments (Figure 1)—to create video sequences of varying durations that provided differing amounts of visual information related to the server's action kinematics.

We created two sets of video sequences: one for testing (pretest and post-test) and one for training (intervention). Two 17-year-old right-handed servers, each with over 12 years of tennis experience and regular participation in international tournaments (mean ITF Juniors ranking 228.5 ± 67.5), were recorded using an iPhone 14 Pro Max (30 fps) and a Canon EOS 4000D (30 fps). A tripod-mounted camera was positioned at the typical location and mean body height of a receiving player (these recordings served only as feedback for the intervention group). A second camera was placed on the server's side, 1 m inside the service line toward the net, aligned between the server and the first camera. This second camera captured the server's full action and the ball's trajectory.

From 58 recorded serves from the deuce court, 12 representative serves (six per server) were selected by an expert tennis coach with over 10 years of coaching experience and prior competitive playing experience at the national level. The selected serves included all three types of first serves (flat, slice, kick), landing legally within the service box either close to the T (junction of the service line and centre line) or wide (near the sideline). Each video was edited to begin with the server's preparation phase and initial stance and then was prematurely terminated at one of the designated occlusion moments with a five-second blackout. Each serve type was occluded at six specific moments (Figure 1). In total, 72 video sequences (12 serves \times 6 occlusion conditions) were created. Video files containing these sequences were then assembled in an identical randomized order for the pretest and post-test, and in a different randomized order for the intervention training.

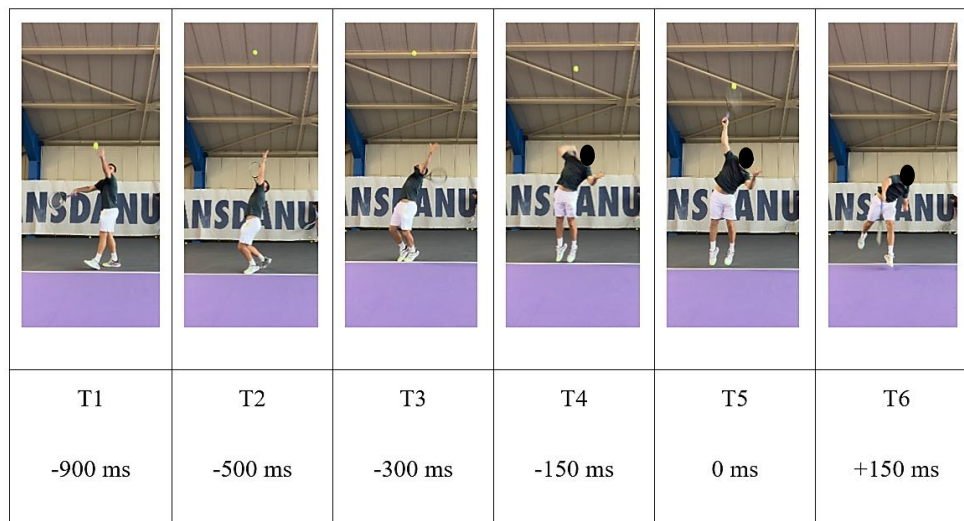


Figure 1. Occlusion points in the video sequences. The T5 (0 ms) condition represents the moment of racket–ball contact.

Pretest

After receiving instructions about the tasks and testing conditions, participants completed the pretest. They were not familiar with the servers featured in the video recordings. The pretest included four practice trials with occlusion and four without occlusion to familiarize participants with the task requirements. The pretest consisted of 72 sequences presented in random order and without sound. Participants were required to watch the videos and respond as quickly as possible by simulating either a forehand return shot (if the serve was aimed wide) or a backhand return shot (if the serve was aimed to the T).

The video sequences were displayed on a screen with a 139 cm diagonal. Participants stood in their normal receiving position with a tennis racket, 4 m from the screen, ensuring that the viewing angle was approximately 6°, corresponding to an in-situ spatial situation. A 6-minute break was provided after 36 trials (i.e., halfway through the test). Participants' responses were recorded on prepared response sheets. The entire pretest lasted approximately 20 minutes.

Intervention

Participants assigned to the intervention group completed 12 perceptual-cognitive training sessions (four times per week over three weeks) in addition to their regular tennis and fitness training between the pretest and post-test (Brenton et al., 2019; Farrow et al., 2005; Müller & Abernethy, 2014). Perceptual training

consisted of watching pretest videos on a tablet or TV screen, supplemented with serve-outcome feedback (i.e., after each occluded sequence, the full server action was shown without occlusion, including the ball trajectory and landing point in the service box). Each training session lasted 14 minutes and included 144 video sequences (72 occluded trials plus full-length feedback videos for each occlusion condition). Before starting the intervention, participants were instructed to: i) watch the video recordings on a screen with a diagonal of at least 25 cm; ii) perform a motor response to each occluded sequence by simulating a forehand or backhand return shot based on the predicted serve outcome (T or wide). By completing all 12 training sessions, participants in the intervention group viewed a total of 864 occluded video sequences, including 144 sequences for each occlusion condition.

Post-test

Two days after completing the intervention, all participants undertook the post-test, which was identical to the pretest.

Statistical analysis

The dependent variable was the response accuracy of participants' motor responses when estimating the correct location of the tennis serve in each occlusion condition. A correct motor response involved simulating a forehand or backhand return shot corresponding to the server's intended direction. Relative correctness was calculated as the proportion of correct responses out of all responses for a given occlusion condition for each participant. This value ranged from 0 to 1 (e.g., 0.60 = 60% accuracy). Due to the small subgroup sizes and potential violations of normality assumptions, non-parametric statistical procedures were applied.

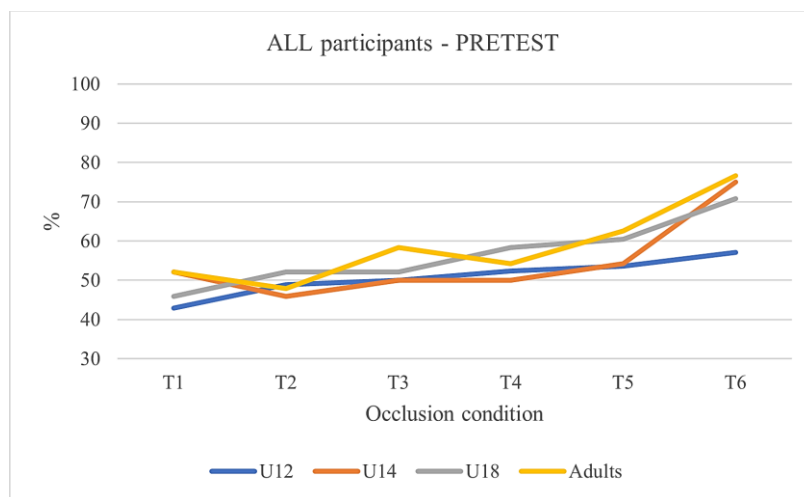
To examine differences in pretest performance across age categories (U12, U14, U18, adults), pooled results from T1–T6 were analysed using the Kruskal–Wallis test. Where appropriate, exploratory pairwise comparisons were conducted using Mann–Whitney U tests. Within-group pre–post comparisons (intervention and control groups separately) were performed using the Wilcoxon signed-rank test. To assess the group \times time interaction effect, change scores (post-test minus pretest values) were calculated for each participant and compared between the intervention and control groups using the Mann–Whitney U test. The data were compared against a 50% guessing level, as only two response options were available. Effect sizes (r) were reported for Mann–Whitney U and Wilcoxon signed-rank tests to support interpretation of practical relevance. Additionally, performance accuracy was descriptively compared against a 50% guessing level, reflecting chance performance when only two response options were available. Due to the small subgroup sizes, statistical findings were interpreted alongside effect sizes and descriptive patterns.

RESULTS

As an initial overall performance of anticipation skills, we present the pretest results of both CG and IG together, with the respect to specific age categories. We observe (Figure 2) comparable correct responses in the early occlusion conditions T1–T4 across all age categories, adults who achieved most successful results in T3 condition from all categories and improved performance in T5 and T6 conditions except U12 category. Although the overall Kruskal–Wallis test was not statistically significant, exploratory pairwise Mann–Whitney U comparisons indicated a possible difference between the U12 and adult categories ($U = 669.5$, $p = .023$, $r = .27$). Given the exploratory and pilot nature of the study, these findings should be considered preliminary.

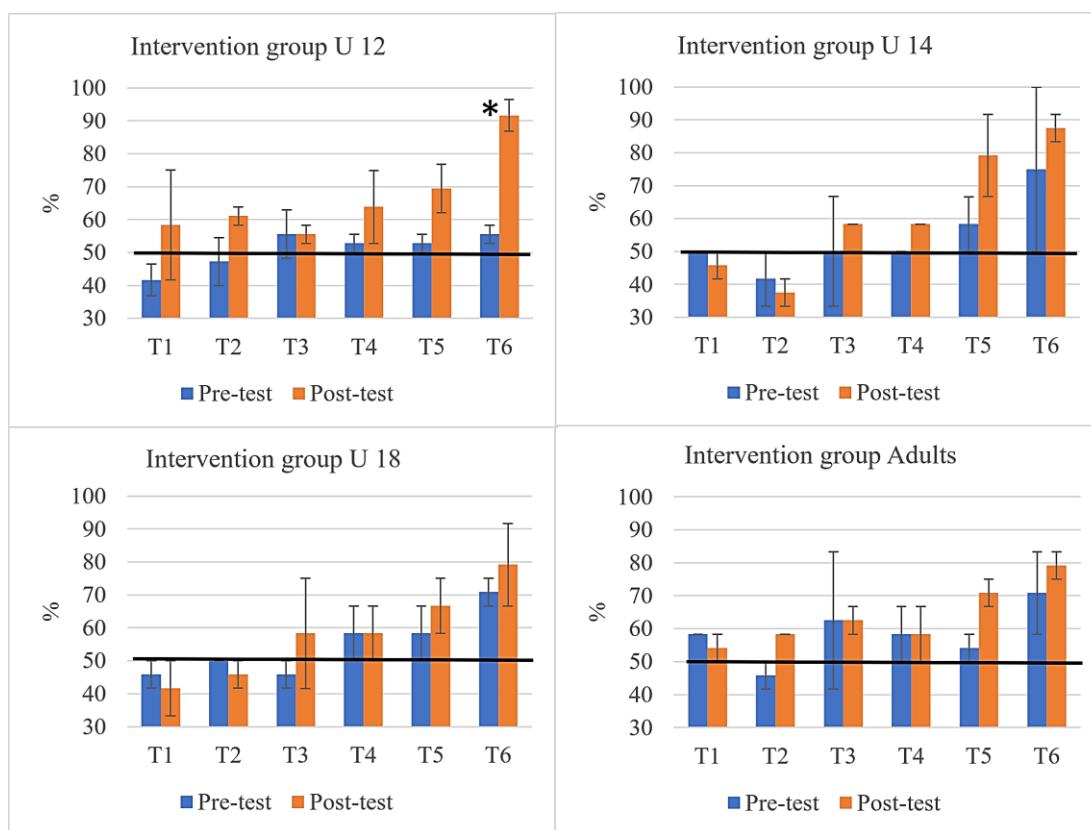
Next, some findings were observed in the pre- and post-test results of the IG (Figure 3) and CG (Figure 4). Using the Mann–Whitney U test to assess the group \times time interaction, non-parametric analyses revealed a

statistically significant effect only in the U12 category under the T6 condition ($U = 0.0, p = .048$), indicating greater improvement in the intervention group compared to the control group. No other age categories or occlusion conditions reached statistical significance.



Note. 50 % guess line is highlighted.

Figure 2. Results of all participants performance during pretest.



Note. *Significant group \times time interaction in U12 under T6 ($p < .05$). The 50% guessing level is indicated by the horizontal line. Error bars represent \pm standard error of the mean (SEM).

Figure 3. Intervention group results of pre- and post-test comparisons by age category.

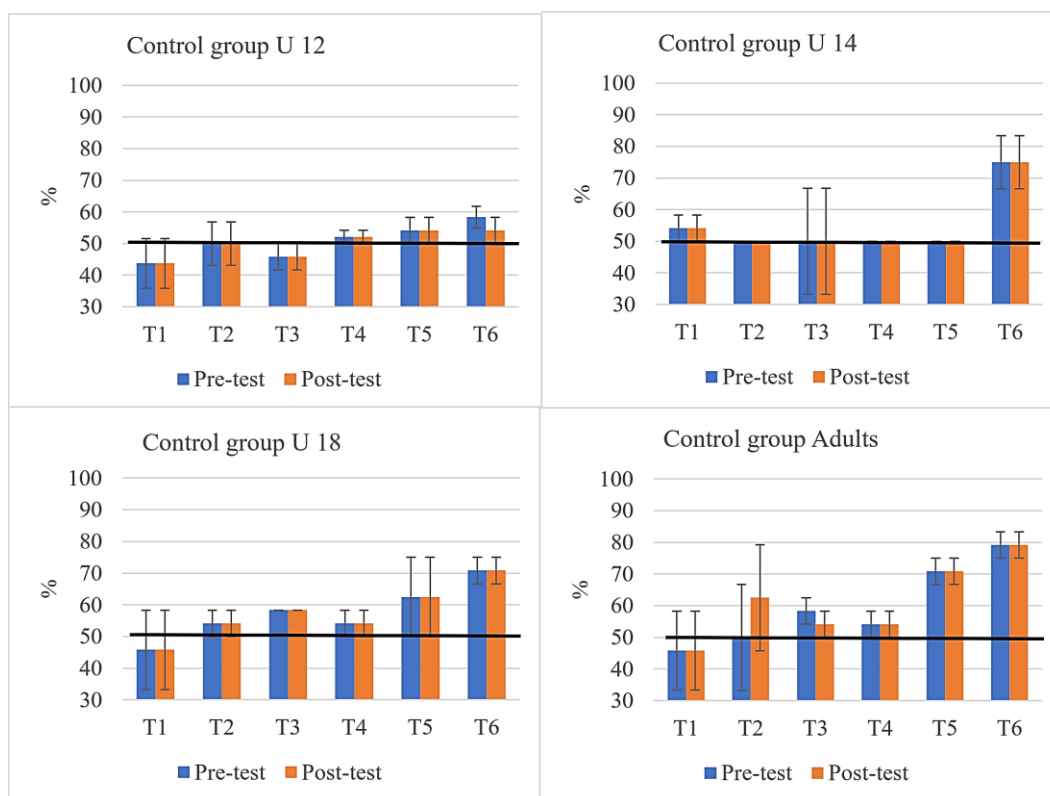
Table 1. Relative percentage values of IG improvement after the intervention.

	T1	T2	T3	T4	T5	T6
U12	16.7	13.9	0	11.1	16.7	36.1
U14	-4.2	-4.2	8.3	8.3	20.8	12.5
U18	-4.2	-4.2	12.5	0	8.3	8.3
Adults	-4.2	12.5	0	0	16.7	8.3

Note. All values are in %. The bold values represent an improvement in performance of over 10% and a success response rate exceeding 60% simultaneously.

The CG reached almost identical results in the pre- and post-test, with U18 and adults had better performance in T5 and T6 occlusion conditions compared to U12 and U14. Within-group pre-post comparisons using the Wilcoxon signed-rank test did not reveal statistically significant changes in either the intervention or control group across any age category or occlusion condition. Interestingly, U12 performance at T6 remained similarly poor (close to 50%) in the IG pretest and CG pre- and post-test. The intervention program showed an effect in IG post-test results.

When evaluating descriptive results based on relative percentages, improvements in correct responses were already observed in the T4 condition in U12; however, the largest improvements occurred in T5 and T6 (for details see Table 1). All age categories improved under T5 and T6, with the greatest relative improvement observed in U12 and U14. In particular, a pronounced improvement was observed in U12 under the T6 condition. Despite this, these results should be interpreted cautiously given the small sample size and should be considered exploratory trends rather than statistically confirmed effects. The present findings should be interpreted as preliminary evidence requiring confirmation in larger controlled investigations.



Note. The 50% guessing level is indicated by the horizontal line. Error bars represent \pm standard error of the mean (SEM).

Figure 4. Control group results of pre- and post-test comparisons by age category.

DISCUSSION

The aim was to assess the effect of perceptual-cognitive training of tennis serves modified by temporal occlusion on the development of anticipatory skills in expert tennis players of various age categories. Given the pilot nature of this investigation, we observed descriptive indications that older and more experienced players demonstrated higher initial anticipatory performance. The perceptual-cognitive training was associated with improvements in anticipatory performance across age categories; however, statistically supported effects were primarily observed in the youngest players under late occlusion conditions. In particular, relative improvements were most apparent in the previously less-developed anticipatory performance of the U12 and U14 categories.

Several noteworthy findings emerged from the present results. Firstly, the IG pretest, CG pretest, and CG post-test demonstrated almost identical performance across all occlusion conditions, with participants showing comparable improvements in response accuracy as occlusion timing progressed. This pattern suggests that, in the absence of perceptual-cognitive training, performance remained relatively stable within comparable age categories. However, the IG demonstrated improved performance in the post-test. These changes may be associated with the perceptual-cognitive training intervention and are consistent with previous findings reported in the literature (Farrow & Abernethy, 2002; Maman et al., 2011).

Next, one of the most noteworthy findings was the apparent effect of the training in the U12 participants. They improved towards a level comparable to adults, particularly in the T4, T5, and especially T6 conditions. The hypothesis was only partially supported, as statistically supported group \times time effects were observed primarily in the youngest category under late occlusion conditions. The T6 occlusion performance in U12 during the pretest and in the CG remained at a relatively low response accuracy compared to other age groups, suggesting that participants may have had difficulty extracting serve-direction information after ball impact. These lower results may be related to temporal constraints not being sufficiently present in U12 due to relatively lower serve speeds. Consequently, younger players may experience less pressure to rely on anticipatory cues, as they potentially have more time during serve delivery. Under such conditions, they may rely more on ball-flight information and reactive responses rather than advance perceptual cues.

However, after the intervention program, pronounced improvements were observed not only in T6 but also in the T5 racket-ball impact occlusion and the T4 pre-racket-ball impact occlusion conditions. This pattern may suggest an increased use of advance kinematic information from the server's actions, such as cues originating from the racket-shoulder region, movement patterns, and the ball toss (Carboch et al., 2018; Vernon et al., 2018), which can vary across serve types and serving locations (Abrams et al., 2014; Reid et al., 2011). Nevertheless, due to the exploratory design and limited statistical power, these interpretations should be understood as hypothesis-generating rather than confirmatory evidence of anticipatory learning.

The U12 category was not the only group affected by the intervention. Descriptive results suggested improvements across the remaining age categories as well. Performance gains were particularly visible from T5 to T6 across all groups and from T4 in the U12 and U14 categories. In these younger categories, response accuracy in the T4-T6 occlusion conditions approached levels comparable to older players. Such changes may reflect adaptations in perceptual processing strategies, potentially involving modifications in visual search behaviour, such as directing gaze toward task-relevant locations for longer durations to extract advance information (Abernethy et al., 1999; Murgia et al., 2014). However, these mechanisms were not directly measured in the present study and therefore remain interpretative. Visual search strategies may also vary substantially across individual players (Murray & Hunfalvy, 2017). The T4-T6 IG post-test results,

particularly the improvement observed in U12 and U14, may indicate that anticipatory performance can respond to relatively short perceptual-cognitive interventions even in younger players, thereby extending previous observations reported by Weissensteiner et al. (2008).

However, it should also be considered that the older categories entered the study with greater playing experience and therefore demonstrated improvements as well. With respect to the results, response accuracy from the T4 occlusion onward did not drop below the 50% guessing level across age categories, and in the IG post-test a similar pattern was already observable from the T3 condition compared to earlier occlusions (T1–T3). Even though the overall magnitude of improvement was modest, the absence of performance decline below the 50% level may indicate that participants were occasionally able to utilize limited advance information, preventing performance from falling to chance level. In general, the IG results suggest improved performance in serve anticipation tasks. In some cases, players may have relied on earlier available kinematic cues, potentially allowing responses to be initiated earlier within the occlusion sequence, which could represent a meaningful temporal advantage during serve return situations. However, such interpretations remain speculative, as the timing of information acquisition was not directly measured in the present study.

Video-based perceptual-cognitive training may support the development of anticipatory performance in young tennis players and represents an accessible method allowing independent practice. Such training may enhance anticipatory performance and has previously been associated with implicit perceptual learning processes (Farrow & Abernethy, 2003; Jackson & Farrow, 2005), and can be applied beyond the tennis court, including home environments or travel situations, thereby improving training efficiency. The authors acknowledge that the findings are based on a small pilot sample; however, consistent with previous pilot investigations (see Müller et al., 2015), the results provide preliminary, hypothesis-generating insights suggesting that anticipatory performance may respond to perceptual-cognitive training even in young athletes.

CONCLUSIONS

After the three-week perceptual-cognitive training application, descriptive improvements in anticipatory performance were observed across age categories. Notably, after the intervention, the U12 group showed pronounced relative improvement, with both the U12 and U14 categories approaching levels of anticipatory performance comparable to the U18 and adult participants. However, these findings should be interpreted cautiously given the small pilot sample and cannot be generalized. The results suggest that perceptual-cognitive training may influence anticipatory performance, with preliminary indications that younger players may improve their use of advance anticipatory information. Given the growing interest in anticipation and perception among professional athletes, the present findings support further investigation and application of such training approaches in future controlled studies. Video-based perceptual training may represent a promising approach to enhancing perceptual and anticipatory skills in junior tennis players.

AUTHOR CONTRIBUTIONS

All authors meet the criteria for authorship in accordance with established ethical guidelines. Contributions are specified according to the CRediT (Contributor Roles Taxonomy) as follows: Conceptualisation: Jan Carboch, John Brenton, Tomas Kocib. Methodology: Jan Carboch, John Brenton. Formal analysis: Kristina Mrazova. Investigation: Kristina Mrazova. Data curation: Kristina Mrazova, Vendula Redlichova, Jan

Carboch. Writing – original draft: Jan Carboch, John Brenton. Writing – review & editing: Jan Carboch, Vendula Redlichova. Supervision: John Brenton, Jan Carboch.

All authors have critically reviewed and approved the final version of the manuscript and agree to be accountable for all aspects of the work.

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CONFLICT OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this manuscript.

AI USE DISCLOSURE

In accordance with current publishing ethics and transparency recommendations, artificial intelligence (AI) tools were used solely to assist with translation and language editing, with the aim of improving clarity and readability. No AI tools were used in the generation of scientific content, including the study design, data collection, analysis, interpretation of results, or the formulation of conclusions. The authors retain full responsibility for the content of the manuscript and confirm its originality, integrity, and accuracy.

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