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# Reactive and Pre-planned Agility in Young Tennis Players

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## ABSTRACT

**Background:** In tennis, movement efficiency can be described as agility, which is crucial for adapting to the fast-paced and unpredictable nature of the game and affects a player's ability to position themselves effectively and react to their opponent's shots. While most studies focus on pre-planned movements, fewer address the cognitive and reactive components that mirror real match scenarios, highlighting the need for a more comprehensive approach to assessing agility in tennis.

**Methods:** The agility of 23 young tennis players (15 boys, 8 girls, aged 14 ± 1.7 years) was analysed using the simplified Tennis-specific Agility Test (TAT). Correlation analyses were conducted to assess relationships between agility components, reaction time, and competitive level.

**Results:** No significant sex-specific differences in agility performance were found. Older players (15 to 17 years) showed significant improvements in both pre-planned and reactive agility ($p < 0.05$). Agility performance correlated moderately with level of play ($\rho = -0.5$), with top national players performing better, particularly in pre-planned agility ($p < 0.05$). Remarkably, reaction time remained constant, even with different performances in both forms of agility. Strong positive correlations were found between pre-planned and reactive agility ($r = 0.7$) and between reaction time and reactive agility ($r = 0.4$). Reaction time explained about 15% of the variability in reactive agility.

**Conclusion:** Our study highlights the need for targeted training to close the gap between pre-planned and reactive agility in tennis. Coaches should focus on reactive agility, reaction time and both physical and cognitive skills to improve on-court movement, considering factors such as age and level of play.

**Keywords:** tennis, movement, agility, reaction time

## INTRODUCTION

The complexity of tennis requires athletes to react quickly and move explosively right from the start. Tennis players must not only be able to move in a straight line, but also sideways and in different directions (Kovacs, 2006). The average number of changes of direction (COD) per point in tennis has been reported to range from approximately 1.6 (Giles et al., 2024) to 4 (Fernandez-Fernandez et al., 2009). However, it is noteworthy that the number of changes can reach to as many as 15 during a single point, and more than 1,000 per match (Kovacs, 2009).

To meet these demands, agility proves to be a crucial physical attribute that enables tennis players to achieve their goals. Its importance and impact on performance was recognised several decades ago (Roetert et al., 1992), when the game was less physically demanding. This emphasises the continued importance of agility, especially in today's increasingly demanding tennis environment where physical skills are constantly being perfected (Roetert & Ellenbecker, 2002).

A comprehensive definition of agility would recognise the physical demands, including strength and conditioning, the cognitive aspects related to motor learning, and the technical skills involving biomechanics that contribute to agility performance (Sheppard & Young, 2006). Agility, along with decision-making, can be considered either a closed or an open skill. Closed skills involve automated movements initiated by the athlete with little uncertainty, while the cognitive aspects of agility are associated with the characteristics of open skills, which involve a constantly changing environment in which players must process and react to information (Čoh et al., 2018), usually to an external visual stimulus under time-limited conditions (Ward et al., 2002). Reactive agility refers to non-preplanned scenarios and is influenced by cognitive components such as anticipation, reaction speed and selective attention, whereas non-reactive agility in pre-planned situations is more determined by COD speed (Sheppard et al., 2006; Sheppard & Young, 2006).

In tennis, pre-planned agility is often assessed together with linear speed tests, as both are important for success in this sport. However, COD performance has a moderate and higher impact on tennis performance compared to linear sprint (Volk et al., 2023). The low to moderate correlation between agility and linear sprint suggests that they should be developed as separate skills for effective movement on the tennis court. A higher correlation is observed between agility and linear 5-metre speed, underlining the importance of starting acceleration. In particular, the development of neuromuscular power can indirectly improve both speed and agility (Munivrana et al., 2015). In a study of young tennis players aged 8 to 10 years, three pre-planned agility tests – 5x10, hexagon and spider test – were conducted. A key finding was that even at this early age, the more advanced players achieved significantly higher scores (Sánchez et al., 2016). The T-test, which is often used to assess agility in tennis, was applied to a group of 33 Indian Junior tennis players with an average age of 15.20±0.41 years. This test was conducted in conjunction with a 5-week core training programme. The significant difference in agility observed strongly suggests that the core training programme contributed to improved agility. The improvement could be due to factors such as improved motor recruitment, improved neural recruitment or better neural adaptation through the core training programme (Bashir et al., 2019). In another study, agility was tested under specific (with tennis racket) and non-specific (without tennis racket) conditions, involving 33 tennis players (13 men and 20 women; age: 18.3 ± 1.1 years and 18.6 ± 1.3 years). The variables included three agility tests: a 20-yard test, a T-test, and the Illinois test, all of which were performed under both specific and non-specific conditions. The Illinois test, with a duration of 20 seconds, raised questions about the appropriate duration and specificity of the movement in relation to actual demands. Nevertheless, the authors found that tennis players performed better during longer agility tests without a tennis racket, while shorter duration agility tests improved performance with the racket (Sekulic et al., 2017). Furthermore, the racquet mechanics of tennis players performing running forehands at different movement speeds can change, emphasising the importance of practising stroke and movement actions in coordination (Giles & Reid, 2021), which highlights the important role of a specific factor in tennis agility.

The primary goal of measurements and training methods is always to adapt them to the sport in order to reflect the actual requirements and characteristics of the game as accurately as possible. Recently, a handful of studies have addressed this problem of agility by developing tennis-specific agility exercises or tests. These tests incorporate perceptual–cognitive skills, the importance of which has been investigated in various sports studies (Schumacher et al., 2019). A tennis-specific agility test places higher demands on athletes as it requires excellent physical, cognitive and combined agility performances and is thus more demanding than conventional COD tests (Jansen et al., 2021). In tennis, the ability to react quickly is crucial. This includes the ability to prepare early, execute a shot and direct the ball precisely to a specific point on the opposite side of the court within milliseconds. This ability to react quickly is important to create challenging situations and put pressure on the opponent and should be practised daily (Senatore & Buzzelli, 2022). Some of the previously mentioned tennis specifics are addressed by a test using an electronic timing system with programmable light stimuli where the athlete has to move quickly from the baseline to three fixed gates in response to light signals (Cooke et al., 2011) or a tennis-specific sprint test using a dual signalling board with two light-emitting diodes (right-left) (Ulbricht et al., 2013). Similarly, the "Speedcourt" system has been developed to assess and train both COD speed and reactive agility. This innovative equipment has been shown to effectively evaluate multi-directional COD, and its training capacity has been demonstrated to improve COD speed and reactive agility in athletes (Düking et al., 2016). Notably, a study demonstrated that random route multi-directional sprint training on the "Speedcourt" was more effective than traditional sprint training in improving reactive agility among collegiate tennis players (Zhou et al., 2024).

Recently, a more complex Tennis-specific Agility Test (TAT) was developed, which includes four movements around the baseline (two sideways, two into the court) and a randomly assigned drop shot. On the opponent's side, four lights simulate the opponent's positions in both standard rally and defensive situations, prompting players to anticipate and react to the paired lights on their side (Jansen et al., 2021). Similarly, a tennis-specific reactive agility test has been developed that requires no special equipment but does require four assistants to administer the test. The test involves responses to visual stimuli, the inclusion of tennis equipment (tennis racket and ball) and the execution of tennis-specific footwork and movements on the court (Munivrana et al., 2022).

While existing studies on tennis-specific agility have primarily focused on assessing pre-planned movements, fewer have incorporated the cognitive and reactive components that mirror the unpredictable nature of real match scenarios. This gap in the literature highlights the need for a more comprehensive approach to assessing reactive agility in tennis. Our study aimed to bridge this gap by capturing the essential tennis-specific demands, including movements, footwork, visual stimuli, and the use of equipment. Recognising that pre-planned and reactive agility are independent yet complementary skills contributing to overall agility (Čoh et al., 2018), our research investigates both components. To capture the key demands of tennis-specific agility in a feasible manner, we adapted existing tests, considering practical limitations in terms of assessors and setup. Additionally, we analyse how these aspects are influenced by reaction time, sex, age, and level of play, providing valuable insights into the factors that impact agility performance in young tennis players.

## METHODS
## STUDY PARTICIPANTS

Twenty-three young competitive tennis players were selected from local tennis clubs. The group, consisting of 8 girls and 15 boys, had a mean ± S.D. age of 14 ± 1.7 years, height of 169.3 ± 9.2 cm and mass of 57.2 ± 11.0 kg. All players actively participated in competitions at national and/or international level and were established on the national ranking list. Among them, 12 players were in the top 15 of the national ranking list. The mean playing experience of the group was 7.9 ± 2.7 years. The study was conducted in accordance with the ethical principles outlined in the Declaration of Helsinki. All participants provided informed consent prior to participation.

## TESTING PROTOCOL

Before testing, all players underwent a warm-up, including a 3-minute jog and dynamic leg stretches (hamstring scoop, forward leg swing, forward hip rotation, one-leg quad stretch, lunge with rotation). Additionally, they performed two submaximal efforts of the upcoming test without the FITLIGHT system. Clear instructions were provided to all participants before the initiation of the test, emphasising the application of tennis-specific movements. This directive encompassed facing forward and incorporating the split step in the middle of the movements, with a constant requirement to return to the starting point. In both testing protocols, participants engaged with four directions/lights, each representing a tennis shot. The FITLIGHT Trainer TM system, known for its speed and cognitive light features, supplied cues for the direction in which participants were to move. The reactive agility assessment involved responding to a sequence of three baseline lights and one drop shot light. The sequence changed randomly, always concluding with one of the dropshot lights. On the other hand, the pre-planned agility sequence also consisted of three baseline lights and one drop shot light. However, unlike the reactive test, the sequence was predetermined and remained constant for every player. The distinction between pre-planned and reactive agility is utilised as a measure of reaction time, as previously suggested by other authors (Cooke et al., 2011). To mirror tennis-specific circumstances, players intercepted the light signals using adjusted tennis racquet (Figure 1), adding a realistic element to the testing environment, as recommended by Sekulic et al. (2017). The tennis racquet used in the study was a standard size and weighed 300 g. It was modified with a cardboard shape attached to the racquet head using small ropes. This cardboard served as an interceptor, ensuring that the signal was intercepted properly, as it would not be captured solely by the strings.

Players underwent both tests three times, with a 120-second rest interval introduced between attempts to facilitate recovery. Acknowledging that 50 – 70% of Creatine Phosphate replenishment occurs within the initial 30 seconds (Crespo & Miley, 1998), and recognising that complete recovery typically demands a minimum of 3 minutes (Morton, 2008), we decided on a rest time of 120 seconds. This decision reflects a balance between practicality and the effective replenishment of Creatine Phosphate.

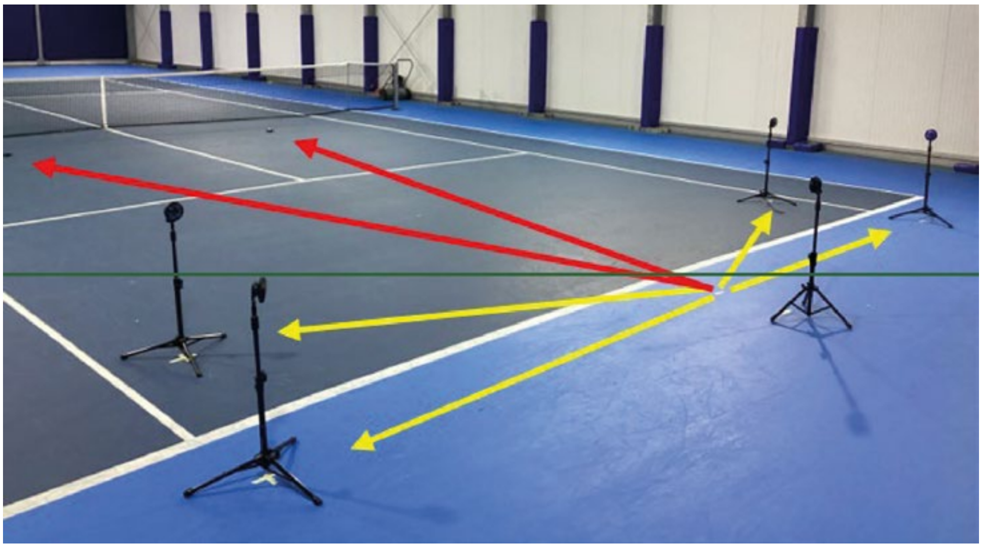
Figure 1**. Adjusted tennis racquet.**

## SET-UP

The set-up was based on the Tennis-specific Agility Test (TAT), with acceptable test-retest reliability and moderate concurrent validity as documented by Jansen et al. (2021). For practical implementation, the test was simplified by excluding the coupling of lights at the opponent side. Participants began 0.5 metres behind the baseline, with measurements taken in six directions – two lateral, two diagonal forward, and two forward – each guided by a specific light cue.

Distinctively, two lateral lights denoted lateral movement, while two forward diagonals signalled offensive diagonal forward movement. Additionally, two forward lights indicated a sprint in response to an opponent's dropshot. All baseline lights were positioned at a height of 0.95 metres, imitating the mean shot contact height observed in Grand Slam events (Reid et al., 2016). The lights were placed 4 metres from the starting point, an average distance covered in a tennis sprint (Kovacs, 2009). Considering the timing of a dropshot, lights representing this shot were strategically placed at ground level, 10 metres from the baseline and 2.1 m from the middle. An additional light was positioned behind the starting position, requiring participants to move back to the starting point after completing each directional movement to activate the next direction (Figure 2). The test was conducted on an indoor hard-court surface (Confosport, Casali Sport, Castelferretti).

Figure 2. **Agility test set-up.**



## STATISTICAL ANALYSIS

To assess differences in agility performance across groups (sex, age group, playing level), we employed independent samples t-tests, first verifying distribution normality through the Shapiro-Wilk test and ensuring homogeneity of variances. For exploring associations, we utilised both Spearman and Pearson correlation coefficients. In delving into the background of relationships associated with reactive agility, we used a linear regression model. To evaluate reliability, we utilised the intraclass correlation coefficient ($ICC_{2,1}$) along with a corresponding 95% confidence interval (95% CI) for ICC. Interpretation of ICC values was categorised as follows: ICC $< 0.50$ as poor, between 0.50 and 0.75 as moderate, 0.75 to 0.90 as good, and ICC $> 0.90$ as excellent (Koo & Li, 2016). The statistical significance of $p \leq 0.05$ was applied. Statistical analyses were conducted using RStudio software (version 4.2.2) and Microsoft Excel spreadsheets from Microsoft Corp. (Redmond, WA, United States).

## RESULTS

Table 1 presents descriptive statistics for all participants, including each agility test (pre-planned and reactive agility) and reaction time. Notably, it illustrates variations in mean values, indicating a 2.7-second difference (reaction time) between the two agility measures.

Table 1. **Results of each agility test and reaction time in seconds.**

| | Min | Max | Mean | SD |
|---|---|---|---|---|
| Pre-planned agility | 9.0 | 12.9 | 10.6 | 0.89 |
| Reactive agility | 12.1 | 15.3 | 13.4 | 0.94 |
| Reaction time | 1.6 | 4.3 | 2.7 | 0.67 |

One of our aims was to investigate whether there are sex differences in agility performance in young tennis players, considering both pre-planned and reactive agility. The analysis showed that boys were on average 0.5 seconds faster when it came to pre-planned agility. However, none of the results showed statistically significant differences between boys and girls in terms of agility performance, regardless of whether it was pre-planned or reactive.

Next, we analysed the age groups and divided the participants into two groups: 12 to 14 years and 15 to 17 years. The expectation was that all three parameters would improve in the older players. Both pre-planned and reactive agility showed statistically significant results, indicating better performance in the older group. However, no statistical differences were found in reaction time. At the same time, the only statistically significant correlation observed was a moderate correlation ($\rho = -0.5$) between age and pre-planned agility. This indicates that there is a moderate tendency for pre-planned agility to improve with increasing age. A weaker ($\rho = -0.3$) and statistically non-significant correlation between age and reactive agility suggests a complex background for reactive agility that does not automatically improve with age.

Our next objective was to assess the relationship between level of play, as measured by national ranking points, and agility performance. Correlation analysis revealed that both pre-planned and reactive agility had a similar moderate correlation with level of play ($\rho = -0.5$). However, when analysing reaction time, no clear correlation trend was found. Better players did not show better reaction times, with a correlation coefficient ($\rho$) of 0.1, suggesting that the differences in reaction time between players of different skill levels were not statistically significant.

Additionally, we analysed playing level in more detail by forming two groups: the top 15 national players and the lower-ranked players. Our analysis revealed differences in favour of the higher ranked players in both pre-planned (Figure 3) and reactive agility (Figure 4). However, statistical significance between the groups was only found for pre-planned agility ($p < 0.05$). No significant differences were found in the reaction time in relation to the players' playing levels.

Figure 3. **Pre-planned agility and playing level.**

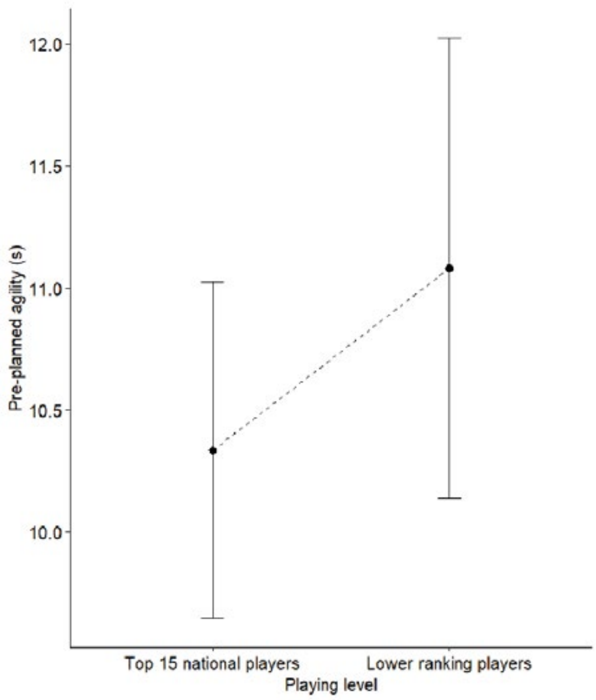
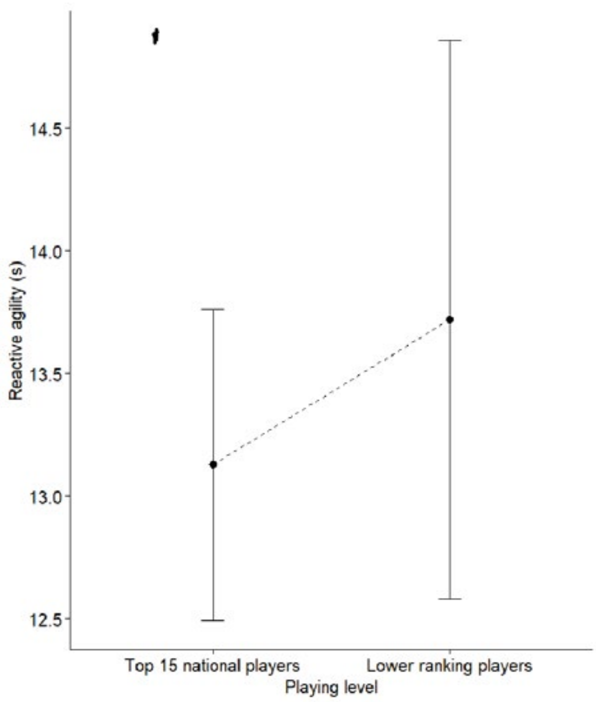



Figure 4. **Reactive agility and playing level.**



In the final phase of our study, we analysed the relationships between the measured variables. A strong positive correlation was found between pre-planned and reactive agility, with a correlation coefficient of 0.7. In addition, a slightly lower, but still positive correlation was evident between reaction time and reactive agility ($r = 0.4$). Importantly, both correlations were statistically significant. To improve our understanding of reactive agility and its relationship with reaction time, we included a linear regression model in our study. The results show that reaction time explains about 15% of the variability in reactive agility. In other words, a 1-second improvement in reaction time is predicted by the model with an average 0.6-second improvement in reactive agility.

Regarding the reliability of the judgements, the results of the study indicate moderate reliability for both pre-planned agility (ICC = 0.63, 95% CI 0.40–0.80, $p < 0.01$) and reactive agility (ICC = 0.64, 95% CI 0.42–0.81, $p < 0.01$).

## DISCUSSION AND CONCLUSIONS

There is a notable lack of research on tennis-specific agility performance, especially when the perceptual-cognitive component is included. Therefore, our primary goal was to conduct a thorough investigation of tennis-specific agility performance, examining both scenarios with and without the perceptual–cognitive aspect. Considering the findings from the most recent systematic review on COD in tennis (Schneider et al., 2023), our study investigated the interaction of factors such as reaction time, age, sex and level of play in relation to agility performance in young tennis players.

Before conducting our research, we hypothesised that there are sex differences in agility, expecting boys to outperform girls. This hypothesis was partially confirmed, as the 5% difference in favour of boys in pre-planned agility is consistent with previous findings that boys in the under-15 age group have lower COD times than girls (Fernandez-Fernandez et al., 2022). However, despite these specific findings, all results were found to be statistically insignificant, suggesting that there are no sex differences, which is consistent with another study on the agility of tennis players (Leone et al., 2006). The mixed results in existing literature call for more research, particularly when examining pre-planned and reactive agility separately, to comprehensively explore sex differences in tennis agility. It is important to note that the age factor may have contributed to these differing results. Our sample comprised young tennis players, with an average age of 14 ± 1.7 years. A significant portion of our age group is in the pubertal phase, during which cognitive-motor development may play a crucial role. For example, there is a suggestion that increased lower-limb strength could positively influence agility (Sonoda et al., 2018), but it is important to highlight that sex differences in muscle strength are typically not observed before the age of 14 (Ramos et al., 1998), which might explain the lack of differences between the sexes in our study.

The next factor we analysed was age, recognising that agility performance can improve "naturally" through growth and maturation and/or training stimuli (Thieschäfer & Büsch, 2022). This implies that older players who are physically better developed and have played tennis for more years and have therefore completed specific training over a longer period (Sonoda et al., 2018), may have improved agility. In our study, both factors were considered, and statistically significant results were found for both pre-planned and reactive agility. This indicates better performance in the older age group (15 to 17 years) compared to the younger group (12 to 14 years). However, no statistical differences were found in reaction time, highlighting the complexity of the various factors that influence reaction time. Factors such as the type and intensity of the stimulus, motivation, attention, concentration and current physical and mental state may contribute to the complex nature of reaction time (Brychta et al., 2013). Our results indicate that while older players achieved significantly better results in both agility measures, the time difference between them (reaction time) remained constant.

The examination of playing performance using both types of agility revealed a moderate correlation with the level of play ($\rho = -0.5$). In particular, a statistically significant difference in pre-planned agility was found when comparing the top 15 players with the lower ranked players. This result is consistent with previous research emphasising the importance of "COD speed" as a crucial factor in tennis performance (Vuong, et al., 2022). However, this pattern was not observed in reactive agility, again emphasising the more complex nature of perceptual-cognitive abilities. When examining the relationship between reaction time and level of play, a parallel situation was observed, similar to the findings related to age. Our hypothesis was that better players would have a better reaction time compared to others. Contrary to our expectations, the results showed that while better players had faster times in pre-planned and reactive agility, there was no significant difference in reaction time. The data suggest that skilled athletes (e.g. more agile) not only react faster in a game or competition, but also more accurately as they are able to anticipate upcoming events (Roca et al., 2011). In simpler terms, more skilled tennis players are better in predicting their opponent's strokes (Williams et al., 2002), which contributes to their overall better performance. Although our test included a complex reaction time, the element of anticipation (predicting the opponent's shots) was missing. This absence may have contributed to the fact that there were no significant differences in reactive agility and consequently reaction time in relation to players' performance levels. However, another tennis study has shown that reactive ability, which includes both simple and complex reaction time in young tennis players, can be improved through specific three-month training programmes (Senatore & Buzzelli, 2022). Additionally, random-route multi-directional sprint training has been found effective in enhancing reactive agility (Zhou et al, 2024). This highlights reaction time as a trainable parameter, distinct from anticipatory skills, even though it involves a genetically determined aspect of psychomotor reactivity (Brychta et al., 2013). These findings could be particularly beneficial for tennis players, as they offer the potential to reduce the measured mean difference of 2.7 seconds between pre-planned and reactive agility.

In the final phase of our investigation, we examined the correlations between the measured variables – pre-planned agility, reactive agility and reaction time. We observed a strong positive correlation between pre-planned and reactive agility, suggesting that players who excel in on-court movement without the perceptual-cognitive aspect also tend to perform well when the perceptual-cognitive component is included. The strong positive correlation observed between pre-planned and reactive agility suggests that mastery of pre-planned agility already contributes significantly to the fulfilment of agility demands. However, the question arises: is it more effective to focus solely on reactive agility, which encompasses both CODs and the reactive component and may offer a different and potentially more comprehensive approach to training? Future research should address this question by comparing different agility approaches and trying to find the optimal balance between the different types of agility to manage the diverse movement demands in tennis.

To effectively measure sport-specific reaction time, it is crucial to design tasks that are tailored to the specific sport and promote the execution of previously learned movement patterns that can be effortlessly coordinated (Yildiz et al., 2020). In line with this principle, our study revealed significant correlations between reaction time and reactive agility. It is worth noting, however, that only 15% of the variability in reactive agility was explained by reaction time. This statistically significant linear model underscores the importance of reaction time in understanding reactive agility, while also highlighting the need to consider the contributions of other variables not included in the model, such as strength, power, concentration, motivation, etc.

Given the increasing importance of movement in tennis, our study thoroughly examines specific aspects of tennis agility. Using a practical and tennis-specific set-up, we tested both pre-planned and reactive agility. Our results show that reactive agility does not necessarily improve with age, but shows a moderate correlation with level of play, suggesting a more complex background than pre-planned agility, which shows a stronger correlation. There is an opportunity to investigate the effectiveness of prioritising reactive agility, encompassing both CODs and the reactive component, as a potentially more comprehensive training approach in tennis. In addition, we observed that reaction time remained constant for both types of agility despite differences in performance. This raises new questions and considerations for training methods aimed at reducing the time delay between pre-planned and reactive agility. With this finding, coaches are encouraged to prioritise different aspects that influence movement abilities, including reaction time, perceptual-cognitive skills, strength, power, anticipation, dynamic balance and more. Further research is needed to explore the role of reaction time in tennis-specific agility, particularly in relation to anticipation. A holistic approach to training can help to improve overall agility and consequently the performance of young tennis players.

## LIMITATIONS OF THE STUDY

This study has several limitations that should be considered. Detecting lights in reactive agility in lateral directions also depended on peripheral vision, making detection more challenging, especially when the random sequence selected lateral directions three times. Additionally, the moderate reliability of the results, with the modified Jansen test showing an ICC of approximately 0.6, suggests that the findings should be interpreted with caution. Another limitation is the lack of biological maturation assessment, which may have influenced results, especially in 12–14-year-olds. Variations in puberty timing, particularly in boys around 14, could impact agility performance. Future studies should consider maturation measures to better understand its role. Furthermore, our study did not account for the important tennis skill – anticipatory ability. Anticipatory skill involves a player's ability to pick up on cues from the opponent, a vital aspect of tennis decision-making and response. Unfortunately, incorporating this skill into our test would significantly complicate the test set-up.

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The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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