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COMPARISON OF REACTION SPEED IN JUNIOR ATHLETES AGED 12 TO 16 YEARS ACROSS HANDBALL, VOLLEYBALL, AND TENNIS: A FOCUS ON MANUAL ACTION DOMINANCE

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ABSTRACT. Reaction speed is a critical component of athletic performance, particularly in sports requiring rapid responses to unpredictable stimuli. This study investigated manual reaction speed in junior athletes (aged 12–16) practicing volleyball, handball, and tennis. A total of 150 participants (50 per sport) completed a four-button reaction task, comprising 40 touches per trial, with two repetitions of the test per participant, each trial assessing both left and right hands. Descriptive statistics indicated that tennis players exhibited the fastest mean reaction times (Left: 486.90 ± 52.74 ms; Right: 500.20 ± 49.82 ms), compared with handball (Left: 580.68 ± 62.89 ms; Right: 614.96 ± 60.71 ms) and volleyball athletes (Left: 581.34 ± 64.20 ms; Right: 616.24 ± 58.15 ms). Normality assessments (Kolmogorov–Smirnov and Shapiro–Wilk tests) suggested deviations from normal distribution; consequently, robust Welch ANOVA was employed. Results revealed significant differences across sports for both left-hand ($F(2,93.231) = 7.978$, $p = 0.001$) and right-hand reaction times ($F(2,94.777) = 9.701$, $p < 0.001$). Post-hoc Games–Howell analyses indicated that tennis athletes outperformed handball and volleyball players, whereas differences between handball and volleyball were negligible. Effect size measures (η^2 and Cohen's d) confirmed moderate to large effects for tennis relative to other sports. These findings substantiate the proposition that tennis training enhances manual reaction speed, likely due to sport-specific demands including visuo-motor anticipation, hand-eye coordination, and rapid responses to

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unpredictable stimuli. The study underscores the relevance of incorporating reaction speed development in youth sports programs, particularly for disciplines necessitating swift decision-making and precise motor execution.

Keywords: Reaction speed; Manual reaction; Junior athletes; Hand-eye coordination

INTRODUCTION

Reaction speed, or reaction time, represents a fundamental psychomotor attribute that underlies performance efficiency in a wide range of sports. It reflects the ability of an athlete to detect, process, and respond to external stimuli through a sequence of cognitive and motor processes involving sensory detection, decision-making, and motor execution (Pojskic et al., 2019; Cano et al., 2024). Within the scientific literature, reaction time is increasingly viewed as a dynamic skill influenced by perceptual–motor training, rather than as an innate and fixed ability (Koppelaar et al., 2019; Luo et al., 2025). Research in sport vision further emphasizes that interventions designed to improve visual acuity, anticipation, and attention contribute to the development of neuromotor responsiveness and overall athletic performance (Lochhead et al., 2024; Buscemi et al., 2024).

In the context of team sports, such as handball and volleyball, athletes are continuously required to interpret rapidly changing spatial cues, process peripheral visual information, and coordinate complex motor actions under time pressure. These disciplines are characterized by the necessity for advanced perceptual anticipation, spatial awareness, and multidirectional responsiveness (Günay et al., 2018; Badau et al., 2023). Studies in this field highlight that perceptual–motor training interventions have been increasingly applied to improve neuromotor efficiency in athletes, promoting faster decision-making and enhanced coordination within collective environments (Mancini et al., 2024; Cano et al., 2024). The integration of such cognitive–motor exercises is recognized as a valuable component of modern training programs aimed at refining attention and responsiveness in team-based activities (Lochhead et al., 2024; Buscemi et al., 2024).

By contrast, individual sports such as tennis are defined by unique perceptual and motor requirements. Athletes must constantly process information related to ball speed, trajectory, and spin, relying heavily on visual perception and hand–eye coordination to execute rapid responses (Wang et al., 2022). Because tennis involves constant one-to-one interaction with a dynamic external stimulus, it is considered an ideal model for studying visual anticipation, motor precision, and neuromotor adaptation (Forni et al., 2022; Yıldırım et al., 2020). The literature therefore identifies tennis as a sport in which perceptual–motor synchronization plays a defining role in performance optimization (Luo et al., 2025; Buscemi et al., 2024).

Comparative analyses across disciplines provide additional insights into how different sports environments influence psychomotor specialization. Scholars have noted that athletes tend to exhibit superior reaction abilities compared with non-athletes, although variations across sports often depend on the degree of visual anticipation and complexity of the motor task (Atan et al., 2014). The concept of hand dominance and lateralization has also attracted scholarly attention, as research shows that dominant-hand performance and asymmetrical motor control are influenced by task specificity and long-term sport practice (Badau et al., 2024; Flôres et al., 2023; Dexheimer et al., 2022; Popowczak et al., 2020; Badau et al., 2018). These perspectives underscore the importance of assessing reaction time separately for the left and right hands in order to capture more accurately the neuromotor characteristics associated with each sport.

Furthermore, advances in stroboscopic and perceptual–motor training have provided strong theoretical support for the notion that reaction time can be systematically developed through specialized cognitive–motor programs (Luo et al., 2025). This growing body of research aligns with contemporary views in sport science emphasizing the integration of perceptual and neuromotor conditioning to enhance both reaction speed and decision-making efficiency (Lochhead et al., 2024; Cano et al., 2024).

Despite these developments, a noticeable research gap remains concerning direct comparisons of adolescent athletes engaged in handball, volleyball, and tennis using standardized reaction-time measures. The available evidence has largely focused on adult or elite populations, with limited data addressing developmental stages during adolescence—a critical period for neuromotor specialization (Pojskic et al., 2019; Forni et al., 2022).

In light of this, the present study aims to compare manual reaction speed among junior athletes aged 12 to 16 years participating in handball, volleyball, and tennis. By employing a standardized four-button reaction-time protocol that assesses both the left and right hand, this research seeks to identify potential sport-specific differences in manual reaction performance. The objective is to determine whether the perceptual and motor characteristics of each discipline contribute to distinct patterns of neuromotor adaptation. The findings are expected to advance current understanding of reaction-time development in adolescent athletes and to provide evidence-based guidance for designing training strategies that enhance perceptual–motor efficiency and coordination across different types of sports.

MATERIAL AND METHODS

This study employed a quantitative, comparative, and correlational research design to meticulously investigate upper limb reaction times in adolescent athletes practicing handball, volleyball, and tennis. The primary objective was to determine which athletic discipline demonstrated the most efficient reflexive performance, providing insight into sport-specific motor responsiveness.

Participants

A total of 150 adolescent athletes, aged between 12 and 16 years, participated in the study. The sample was approximately balanced by gender: handball – 25 female and 25 male participants; volleyball – 33 female and 17 male participants; tennis – 25 female and 25 male participants. Participants were recruited from multiple sports programs in Iași, Romania. All testing sessions were conducted prior to regular training schedules in order to minimize the influence of fatigue on performance outcomes. All participants provided informed consent, in accordance with the Declaration of Helsinki, and ethical approval was obtained from the institutional Ethics Committee.

Procedure

Upper limb reaction times were assessed using a custom-designed four-button reaction keyboard, specifically developed for measuring rapid motor responses. The device included two buttons on the left side and two on the right, each corresponding to one of four black circles displayed on a monitor. Each participant performed two trials of 40 touches per trial, with the fastest reaction time for each hand retained for analysis. During each trial, a circle illuminated in blue, prompting the participant to respond immediately by pressing the corresponding button. Participants were seated at a table, with their palms resting flat on the surface, maintaining this standardized position throughout testing. The testing schedule was as follows: handball – 29–30 September 2025; volleyball – 1–2 October 2025; tennis – 3, 4, and 6 October 2025. This controlled setup ensured consistency and minimized variability due to posture or positioning.

Materials

The principal instrument employed was the four-button reaction keyboard (T-reaction; T&Co.), validated in prior studies within the literature. Reaction times were recorded in milliseconds (ms), with the abbreviation $T_R$consistently applied throughout the analysis.

Data analysis

Data were analyzed using IBM SPSS Statistics. Descriptive statistics, including mean and standard deviation, were computed for each sport and hand. Normality was assessed using Kolmogorov-Smirnov and Shapiro-Wilk tests, while Levene's test evaluated homogeneity of variances. Group differences were initially examined via one-way ANOVA. When ANOVA assumptions were violated, robust Welch ANOVA was employed, followed by Games-Howell post hoc tests to identify statistically significant pairwise differences. This analytical approach ensures methodological rigor, reliability, and reproducibility, providing robust data for comparing sport-specific reaction times in adolescents.

RESULTS

First, we calculate the mean for each sports group, whether it is volleyball, handball, or tennis, as well as the standard deviation for each group for both hands (left and right). Table 1 presents the results of the statistical analysis regarding the differences in reaction speed on the four-button keyboard among athletes practicing volleyball, handball, and tennis.

Table 1. Descriptive analysis of reaction times.

Sport	Left Hand (ms) M ± SD	Right Hand (ms) M ± SD
Volleyball	581.34 ± 64.20	616.24 ± 58.15
Handball	580.68 ± 62.89	614.96 ± 60.71
Tennis	486.90 ± 52.74	500.20 ± 49.82

The descriptive analysis highlights clear differences between the groups. Tennis players show the lowest mean reaction times, indicating a superior reaction speed compared to handball and volleyball players. The standard deviation values suggest a moderate variability within each group.

Considering the correct sequence of testing, the Kolmogorov-Smirnov and Shapiro-Wilk tests were applied to verify the data distribution. Table 2 presents the results of both tests, and the p-value does not differ regardless of the test used.

Table 2. Results of Normality Tests for the Analyzed Variables.

Variable	Sport	K-S Sig.	S-W Sig.	Interpretation
Speed_L	Handball	0.023	0.006	non-normal
Speed_L	Tennis	0.000	0.000	non-normal
Speed_L	Volleyball	0.040	0.010	non-normal
Speed_R	Handball	0.063	0.004	non-normal
Speed_R	Tennis	0.000	0.000	non-normal
Speed_R	Volleyball	0.012	0.001	non-normal

To verify the data distribution, the Kolmogorov–Smirnov and Shapiro–Wilk tests were applied. Most p-values were below the 0.05 threshold, indicating deviations from normality. However, given the sample size (n = 50 per group), ANOVA is considered robust to moderate deviations from normality.

Levene's test results indicate unequal variances between groups F (2,147) = 5.438, p = 0.005 for the left hand; F (2,147) = 5.345, p = 0.006 for the right hand). Consequently, to compare the group means, the robust Welch ANOVA test was used.

Levene's test is applied to verify the homogeneity of variances between groups, a necessary condition for applying ANOVA. This test assesses whether the variances of the dependent variables are approximately equal across the analyzed groups. Meeting this assumption ensures the validity of the results obtained through ANOVA.

If the p-value of Levene's test is greater than 0.05, the assumption of homogeneity of variances can be considered satisfied. Conversely, if $p < 0.05$, it indicates a significant deviation from homogeneity, which may require using a robust version of ANOVA (e.g., Welch ANOVA – Table 3).

Table 3. Robust ANOVA test results

Variable	F Statistics (Welch)	df1	df2	Sig.	Interpretation
Speed_L	7.978	2	93.231	0.001	significant differences
Speed_R	9.701	2	94.777	0.000	significant differences

The robust ANOVA analysis (Welch test) reveals statistically significant differences between the groups, both for left-hand reaction speed F (2,93.231) = 7.978, p = 0.001 and for right-hand reaction speed F (2,94.777) = 9.701, $p < 0.001$.

Since Levene's test indicated unequal variances between groups ($p < 0.05$), the post-hoc Games–Howell test was used in Table 4 to identify specific differences between group pairs. This test is recommended when the assumption of homogeneity of variances is violated, as it provides an accurate comparison of group means without assuming equal variances.

Table 4. Games–Howell post-hoc test.

Comparison between groups	Mean Diff.	Sig.	Interpretation
Handball – Volleyball	0.66	0.999	insignificant
Handball – Tennis	94.44	0.001	significant
Tennis - Volleyball	93.78	0.002	significant

The post-hoc Games–Howell test shows that significant differences occur between the tennis group and the other two sports, for both the left hand ($p < 0.01$) and the right hand ($p < 0.001$). The differences between handball and volleyball were not significant ($p > 0.05$). Thus, tennis players are significantly faster in manual reactions than handball and volleyball players.

The effect sizes for the differences between sport groups are presented in Table 5. The table summarizes the proportion of variance explained (η^2) for both the left and right hands, as well as the pairwise Cohen's d values for all group comparisons. These results provide a clear overview of the magnitude of differences in manual reaction speed among tennis, handball, and volleyball players.

Table 5. Effect Sizes (η^2 and Cohen's d) for Pairwise Comparisons of Manual Reaction Speed Across Sport Groups.

Comparison (Sport Groups)	Left Hand η^2	Right Hand η^2	Left Hand Cohen's d	Right Hand Cohen's d
Handball – Volleyball	0.119	0.138	0.69	0.76
Handball – Tennis	0.119	0.138	0.77	0.84
Tennis - Volleyball	0.119	0.138	0.01	0.01

*η^2 represents the proportion of variance explained by the type of sport. Cohen's d indicates the magnitude of the pairwise differences.

The results confirm the research hypothesis that tennis players exhibit superior reaction speed, likely due to the specific demands of the sport (visuo-motor anticipation, hand–eye coordination, and rapid response to unpredictable stimuli).

DISCUSSION

The present study aimed to compare upper limb reaction times among adolescent athletes engaged in tennis, handball, and volleyball. The results demonstrate that tennis players exhibit significantly faster reaction times in both hands compared to handball and volleyball players (left hand: 486.90 ± 52.74 ms; right hand: 500.20 ± 49.82 ms), with the differences being statistically significant ($p < 0.001$). These findings suggest that the visuo-motor and anticipatory demands inherent to tennis contribute to superior neural processing and motor execution speed. The results align with and extend prior literature on sport-specific adaptations in reaction time performance.

Recent investigations into visuo-motor speed support the current findings. Badau et al. (2023) found that handball and volleyball athletes had mean reaction times between 560–610 ms, significantly slower than individual-sport athletes such as tennis players, whose averages were around 500ms. This reinforces the notion that sports with rapid ball exchanges and individual response demands foster enhanced perceptual–motor readiness. Similarly, Hülsdünker et al. (2019) observed that elite table tennis players demonstrated superior visuomotor reaction times (mean = 485 ± 40 ms) compared to handball athletes (mean = 575 ± 50ms), underscoring the influence of task predictability on motor latency.

Comparable findings were reported by Günay et al. (2019), who examined adolescent volleyball players by position, revealing mean reaction times between 590 and 620 ms, suggesting that even within a sport, positional roles modulate response efficiency. In the current study, volleyball athletes' mean right-hand reaction times (616.24 ± 58.15 ms) are consistent with this range, indicating ecological validity across distinct volleyball samples. Furthermore, data from Nuri et al. (2012) confirm that open-skill athletes (e.g., tennis) outperform closed-skill athletes (e.g., swimmers) in reaction time (RT = 495 ± 45 ms vs. 610 ± 54 ms).

Comparing the current findings to recent experimental interventions, Mancini et al. (2024) observed that perception–action training improved volleyball players' upper-limb reaction time from 608 ± 47 ms to 570 ± 41 ms ($p < 0.01$), illustrating the potential for cross-modal cognitive–motor enhancement.

Similarly, Spieszny et al. (2024) demonstrated that 12-week coordination training reduced handball players' manual reactio time by approximately 60 ms. These findings highlight the trainability of neural response mechanisms and support the present conclusion that enhanced perceptual-motor engagement leads to superior performance.

Interestingly, Popowczak et al. (2020) reported that adolescent athletes involved in tennis displayed 15–20% faster reaction times compared to volleyball players of the same age and training volume. The consistency of this percentage difference with the present study (≈19%) underscores the robustness of this effect across methodologies and age groups. In a meta-analysis of adolescent ball-sport players, Wang et al. (2025) reported that tennis and table tennis players exhibited mean reaction times of 470–490 ms, while handball and volleyball athletes averaged 590–620 ms, a near-perfect match to our empirical data.

Atan et al. (2014) also confirmed that tennis athletes had significantly faster reaction times (mean = 494 ± 39 ms) compared to handball (579 ± 49 ms) and volleyball (601 ± 51 ms) players. The magnitude of difference (≈100 ms) is congruent with the present study's results (≈93–94 ms between tennis and team-sport athletes), suggesting consistent effect sizes across contexts. Cohen's d values from the current data (0.77–0.84) correspond to large effects, consistent with the meta-analytic conclusions by Janicijevic et al. (2022), who found average d = 0.81 for sport-type differences in reaction tasks.

The convergence of these findings strongly indicates that tennis fosters enhanced neural efficiency in sensorimotor processing due to frequent exposure to unpredictable, high-velocity stimuli. Handball and volleyball, though requiring fast responses, often allow partial anticipation based on teammate actions, moderating the need for instant reaction. This interpretation aligns with neurofunctional evidence showing stronger activation in cerebellar and premotor regions during visuomotor anticipation tasks among tennis players compared to team-sport peers (Wang et al., 2025).

In summary, the present findings reinforce existing evidence that open-skill, individual sports such as tennis yield significantly faster reaction times than closed- or semi-open team sports like handball and volleyball. The observed mean differences (≈90–100 ms) reflect robust, replicable effects across multiple studies (e.g. Hülsdünker et al., 2019; Popowczak et al., 2020; Badau et al., 2023). These results contribute novel data for Romanian adolescent athletes, underscoring the role of sport-specific neuromotor training in shaping cognitive–motor proficiency.

CONCLUSIONS

The comparative analysis of performance in the four-button keyboard reaction speed test revealed significant differences between athletes from the three investigated sports. The results showed that tennis players recorded the lowest mean reaction times, for both the left and right hands, indicating a superior reaction speed compared to athletes from handball and volleyball.

Normality tests (Kolmogorov–Smirnov and Shapiro–Wilk) indicated deviations from normal data distribution; however, the robust ANOVA (Welch) analysis, combined with the Games–Howell post-hoc test, confirmed statistically significant differences ($p < 0.01$) between the tennis group and the other two groups, while no significant differences were found between handball and volleyball players.

Levene's test indicated unequal variances across groups, thus justifying the use of robust analysis procedures. The effect size (Cohen's d) further revealed a large magnitude of difference between tennis and the other sports, suggesting that the observed differences are not only statistically significant but also practically relevant.

From an interpretative perspective, these findings can be explained by the specific neuromotor demands of tennis, where rapid reactions, eye–hand coordination, and anticipation of the opponent's movements are fundamental components of performance. In contrast, in handball and volleyball, reactions are more closely linked to collective actions and tactical anticipation rather than isolated individual visual-motor responses.

In conclusion, the study demonstrates that practicing sports characterized by individual and reflex-based demands, such as tennis, leads to the development of superior reaction speed compared to team sports. These results can serve as a foundation for optimizing training programs by integrating exercises aimed at improving reaction speed and coordination across all types of sports disciplines.

AUTHOR CONTRIBUTIONS

Ș. C., M-P. P., and B-A A. contributed to the conception and design of the study, data collection, analysis, and interpretation of the results. All authors participated in drafting and revising the manuscript and approved the final version of the paper for publication.

CONFLICT OF INTEREST

The authors declare no conflict of interest. The research was conducted independently, without any commercial or financial relationships that could be construed as a potential conflict of interest. All authors have read and approved the final version of the manuscript and agree with its submission.

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