Waldziński *et al. BMC Sports Science, Medicine and Rehabilitation* (2024) 16:190
https://doi.org/10.1186/s13102-024-00978-3

BMC Sports Science, Medicine and Rehabilitation

RESEARCH

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One-year developmental changes in motor coordination and tennis skills in 10–12-year-old male and female tennis players

Tomasz Waldziński[1*], Ewa Waldzińska[1], Aleksandra Durzyńska[1], Bartłomiej Niespodziński[2], Jan Mieszkowski[3] and Andrzej Kochanowicz[3]

Abstract

Background To date, no longitudinal studies of quarterly changes have been conducted on the differences in the development of motor coordination between boys and girls in relation to changes in their tennis skills level. Therefore, the aim of the study was to assess the development of motor coordination of 10–12-year-old tennis players over the course of 1 year, in the light of changes in tennis skills preparation.

Methods One-hundred eighty male and female tennis players aged 10, 11, or 12 years old participated in the study. Each age group comprised 30 boys and 30 girls. To investigate their motor coordination development, a battery of general tests (simple reaction, complex reaction, Spalding test, spider test, hexagon jumping, Starosta's test, hand–eye test, balance, plate tapping, jump rope) and specific tennis skills tests (wall game and 100-tennis ball tests) were performed 4 times quarterly over 1 year. Differences between sexes and the time points were assessed. The rate of development evaluation was based on beta coefficient of linear regression.

Results Boys generally performed better in tennis skills tests than girls. The boys performed better also in one motor coordination test (Spalding test) among 10-year-olds, in two additional tests (spider and plate tapping tests) among 11-year-olds, and another three more tests (simple reaction, complex reaction and Starosta's tests) among 12-year-olds. Jump rope test among 10-year-olds and hexagon jump test among 12-year-olds were the only tests where girls performed better than boys. On the other hand, girls showed higher rate of development in balance and complex reaction tests than boys.

Conclusions We conclude that motor coordination and tennis skills development over 1 year is age-, sex-, and task-dependent, with the 10–12-year-old male tennis players performing better in tennis skills and overall motor coordination than females.

Keywords Racket sports, Physical fitness, Eurofit test, Performance, Training

*Correspondence:
Tomasz Waldziński
twaldzinski@al.edu.pl
[1]Faculty of Health Sciences, University of Lomza, Lomza 18-400, Poland
[2]Department of Biological Foundations of Physical Education, Faculty of Health Sciences and Physical Education, Kazimierz Wielki University, Bydgoszcz 85-064, Poland
[3]Department of Gymnastics and Dance, Gdańsk University of Physical Education and Sport, Gdańsk 80- 336, Poland

Background

Tennis is a combination of mainly open complex motor tasks, appealing to physical fitness, motor coordination, tactical skills, concentration, mental toughness, self-regulation, and social skills [1]. According to the International Tennis Federation, the most important factors shaping the sports championship of tennis players are reaction time, speed, and motor coordination [2]. Motor coordination describes the ability to adapt movement patterns and adjust the forces to complete a movement task successfully [3, 4], and are considered essential from the perspective of their impact on the game of tennis [5–10]. Tennis coaches suggest that kinaesthetic differentiation and reaction ability are the two most important motor coordination abilities of tennis players [11]. Achieving high performance in tennis requires all-rounder repertoire of moves, and the ability to quickly and flexibly adapt to the ever-changing playing conditions [12–15]. Specific to tennis is the large variation of rotation and the accompanying flight that can be applied to the ball during a rally. This might imply better than motor coordination in the fine ball-handling skills. In addition, players should develop outstanding technical skills; fast switching capability to adjust stroke technique; variable, flexible, and fast footwork; excellent ability to react and anticipate; proper positioning; and balance control [16, 17].

Tennis training is a complex process, spread over time and divided into stages (sets) depending on the age of the tennis player [18]. Typically, children start tennis training at the age of 5–6, and their tennis skills develop along with basic movement skills and physical development (Stage I). One of the crucial time periods in tennis player development is the age of 9–12 (Stage II). It encompasses the optimal time window for motor skill development and thus, it is a critical time for developing fundamental athlete skills and tennis movements [18]. According to experts [19], motor coordination preparation should constitute approximately 30% and 20% of the overall training time in 8–10-year-old and 11–12-year-old athletes, respectively. Having said that, while the basic motor coordination of children at that age is well developed, the specific demands of tennis necessitate further motor coordination development and mastering of the tennis skills. Indeed, 5 weeks of additional motor coordination training were shown to enhance the service technique in 9–13-year-old tennis players [11]. Further stages (III, IV), overlap each other and focus on the competing and winning of adolescent and young adult tennis players. In these stages, motor coordination is being further developed and mastered in conditions of tennis competition.

Previous studies involving cadet and junior tennis players revealed that 80% of all errors during the game are caused by the loss of balance during the stroke [20, 21]. Balance at an appropriately high level contributes to accurate and precise performance of specific movement activities in tennis [17, 22]. In addition to static balance, dynamic balance and the related proprioceptive sensation seem to be extremely important in tennis [23]. Because on the tennis court, in addition to linear sprints, the player performs many movements involving eye-hand coordination, quick manoeuvres and movements related to body pivot, balance seems to be one of the crucial motor skills ensuring outstanding results in competitions [24, 25].

Research has shown that women have better body balance than men. Among others, since the position of the body mass centre of women is relatively lower than that of men [26, 27], women and also girls exhibit a better static body balance than men and boys [28, 29]. However, from the broader perspective of differences in motor coordination between boys and girls, the boys' hand–eye coordination is better than that of girls as early as at 8 years of age, and persists until mid-adolescence [30]. Such differences could influence the process of development of motor coordination and technical skills necessary to achieve mastery in tennis among boys and girls.

Scientific researchers and sports practitioners all indicate the need to monitor the level and dynamics of motor coordination development. Since in many tennis clubs, training at the initial stage is co-educational, insight into these mechanisms would allow coaches to prioritize certain performance characteristics in training exercises, keeping in mind the potential differences between boys and girls, and different age categories. In this manner, training could be tailored to individual needs and, as such, might be more effective with regard to performance improvement. To date, no longitudinal studies have been conducted on the differences in the development of motor coordination between boys and girls in relation to changes in their tennis skills level. Therefore, the aim of the current study was to assess 1-year development of motor coordination skills among 10–12-year-old male and female tennis players, in the light of changes in tennis-specific preparation. Based on previous studies, we hypothesized that rate of 1-year development of motor coordination skills will be higher in younger groups while rate of tennis skill development will be higher in older athletes. Moreover, we hypothesized that female tennis players will exhibit different rate of development than males when it concerns balance related skills.

Methods

Participants

One-hundred eighty young tennis players from clubs of the Podlaskie Voivodeship (Poland) took part in the study. Groups of 10-, 11-, and 12-year-old boys and girls were included in the study. The participants were divided into six groups based on sex and age, with 30 individuals per group. Their basic anthropometric characteristics were determined twice: at the beginning of the study and 9 months later, on the day of the last motor coordination assessment (Table 1).

The participants have been practicing tennis since they were 6 years old, and those in particular groups were at a similar level of sports advancement. The tennis players enrolled for the study were at a high sport level determined on high ranking position on the classification lists of the Polish Tennis Association (at least in the top 70 in his age category). The participants systematically took part in tennis tournaments at the national level. Training classes were held based on the age category. In the study, 10-year-old girls and boys participated in three tennis training sessions (1.5-hour each) per week, while 11- and 12-year-old girls and boys participated in four sessions (1.5-hour each) per week with the exception of April and October, in which, due to the detraining period, the number of tennis training sessions was reduced in each group. The participants underwent training according to their annual framework training plan (Table 2).

The study was conducted in accordance with the Declaration of Helsinki and approved by the Bioethics Committee at Gdansk (KB-25/20). Legal guardians of all participants provided informed written consent to participate in the study prior to the study.

Design and procedures

Motor coordination abilities and tennis skills were assessed four times, quarterly (March, June, September, December), for each participant. The selected time points reflect players' performance during the first preparatory period, the competition period, the second preparatory period, and the second competition period in the tournament calendar planned by the Polish Tennis Association. The assessments took place on Saturdays (motor coordination tests) and Sundays (tennis skills test). All tests were carried out at the same time and in the same sports hall, on artificial surface (Gerflor TARAFLEX type, Lyon, France), after a 10-minute warm-up.

Motor coordination tests

Each participant performed ten motor coordination tests. The selected tests reflect the specificity of the game of tennis. After familiarization with the procedure, each test was repeated twice and the better result was included in analysis. Based on previous research [31, 32] the ICC values for all tests fall within the range of 0.85–0.99; therefore, all tests were considered reliable. The tests were carried out in the following order: simple reaction test, complex reaction test, Spalding test, ball-collecting 'spider test', hexagon jumping test, Starosta's test, hand–eye test, balance test, plate tapping test, and jumping rope test.

Table 1 Anthropometric characteristics of the study participants (mean ± standard deviation, $n = 180$)

	10-year-olds				11-year-olds				12-year-olds			
	Girls ($n = 30$)		Boys ($n = 30$)		Girls ($n = 30$)		Boys ($n = 30$)		Girls ($n = 30$)		Boys ($n = 30$)	
Measurement	I	II	I	II	I	II	I	II	I	II	I	II
Body mass (kg)*	37.09 ± 5.78	38.18 ± 5.81	35.29 ± 4.06	36.52 ± 3.65	38.27 ± 3.79	40.20 ± 3.69	39.07 ± 4.51	40.76 ± 4.52	44.77 ± 5.25	46.79 ± 5.26	44.87 ± 4.35	46.56 ± 4.26
Body height (cm)*	141.10 ± 5.02	143.63 ± 4.72	142.53 ± 5.41	144.53 ± 4.90	148.70 ± 3.41	151.80 ± 3.43	148.53 ± 4.40	150.73 ± 4.01	155.77 ± 5.81	158.60 ± 5.75	155.30 ± 5.39	157.53 ± 5.48

I, assessment in March; II, assessment in December. *Significant difference in I vs. II comparison for each sex and age group ($p < 0.01$).

Simple reaction test

The rate of psychomotor reaction to simple light stimuli emitted at the imposed pace was examined using Piórkowski's apparatus (Alfa-Electronics, Ustrzyki Dolne, Poland). The task consisted of pushing, as quickly as possible, the button below the corresponding light that randomly appeared on the screen of the apparatus [33]. In the study, the light appeared at the rate of 60 times per min. The test result was the number of correct in-time pushed buttons, expressed as the percentage of the maximum possible score (60/60).

Complex reaction test

The rate of the complex reaction, which depends on spatial orientation, psychomotor speed, eye–hand coordination, ability to focus, the speed and accuracy of perception, and the speed of decision making, was examined with the use of cruciform apparatus (Alfa-Electronics, Ustrzyki Dolne, Poland), a complex visual–motor testing device. The device consists of a quadratic 7×7 grid of buttons with a row of 7 lights above the grid and a column of 7 lights on each side of the grid, corresponding to the buttons [33]. Individual light points (one in each row and column) randomly lit up during the test at an imposed pace of 50 times per min. To complete the test, the subject had to press the correct button located at the intersection of rows and columns and indicated by two separate lights coming on (one along the top and one along the side). The test result was the number of correct in-time pushed buttons, expressed as the percentage of the maximum possible score (50/50).

Spalding Test

The task was to complete the circumference of one half of the singles court around markers placed at the intersection of the service line and court sidelines, and in the centre of the service line, a racket's length from the net (three mini-loops around the markers) in the shortest possible time. The test started at the court baseline next to the centre marker. The subject began in the starting forward lunge position and started on the command of 'get ready, get set, go'. The measurement was recorded by a stopwatch with an accuracy of 0.1 s.

Spider test

The test involved collecting five tennis balls on the strings of the racket head, in a given sequence, in the shortest possible time [9]. The five tennis balls were previously arranged, as follows: at the intersections of the baseline and service line with the singles sidelines, and at the intersection of the service line and the centre line dividing the service diamonds. The racket was positioned with its head tangential to the baseline in the centre and with its long axis perpendicular to the baseline. The subject was allowed to carry only one ball at a time; thus, the whole circuit consisted of 10 sections with a total length of approximately 55.5 m. The subject began in the forward lunge starting position and started on the command of 'get ready, get set, go'.

Hexagon jumping test

The subject stood in the centre of a hexagon (side length of 60 cm) marked on the court, facing the net, and performed jumps with both feet over each side of the hexagon, one by one, returning to the centre after each jump. The attempt began after the command 'get ready, get set, go' and ended after three series of jumps around all sides of the hexagon, after touching the starting point. The measurement was recorded with an accuracy of 0.1 s. Half a second was added for each touch of the line and 1 s was added when changing the order of hops [34].

Starosta's test

In the test, Starosta's coordination measurement equipment [35] was used, namely, a wooden platform with a surface area of 1 m^2, with an inscribed circle with a diameter of 0.80 m, on which a scale from 0 to 360 degrees was depicted. The subject stood in the centre of the circle, with the 0 degrees mark between both feet, and jumped up with a maximum rotation to the right and landing on both feet. The obtained result was calculated in degrees, assuming the starting position of 0 degrees mark between both feet. Next, the subject jumped up, with a maximum rotation to the left. The two obtained results were added, and the final result was recorded with an accuracy of 10 degrees.

Hand–eye test

The test was introduced by Faber et al. [15] and is a part of the KTK3+ (Körperkoordinationstest für Kinder) test [36]. The subject stood at a distance of 2 m from the wall, holding a tennis ball in their right hand. Upon the instructor's command 'get ready, get set, go', the subject threw the tennis ball against the wall with the right hand and then proceeded to catch it with the left hand, and then threw the tennis ball with the left hand, and caught it with the right hand (one cycle). The subject performed as many cycles of throwing the ball against the wall and catching it as possible within 30 s.

Balance Test

The subject stood with one leg (the preferred leg) on a beam (50 cm long, 4 cm high, and 3 cm wide), along its longitudinal axis, grasping the opposite knee-flexed leg by the foot, while the other hand rested on the person conducting the test (the trainer). The test began (stopwatch timer ON) when the subject let go of the trainer, and continued until they lost their balance, e.g. releasing

Table 2 Annual framework training plan ($n=180$)

Quarter of the year	I			II			III			IV		
Age	**10-year-olds** ($n=60$)	**11-year-olds** ($n=60$)	**12-year-olds** ($n=60$)	**10-year-olds** ($n=60$)	**11-year-olds** ($n=60$)	**12-year-olds** ($n=60$)	**10-year-olds** ($n=60$)	**11-year-olds** ($n=60$)	**12-year-olds** ($n=60$)	**10-year-olds** ($n=60$)	**11-year-olds** ($n=60$)	**12-year-olds** ($n=60$)
Average number of technical and tactical tennis training sessions per week (h)	4.5	6	6	3.5	5	5	4.5	6	6	3.5	5	5
Average number of general development training sessions per week (h)	1	1.5	2	1.5	2	3	1	1.5	2	1.5	2	3
Average number of physio training – training with a physiotherapist per week (h)	1	1	1	1	1	1	1	1	1	1	1	1
Average amount of mental training per week (h)	0	0	1	0	0	1	0	0	1	0	0	1
Average number of tennis sparring per week (h)	1	1	2	1	1	2	1	1	2	1	1	2
Average number of starts in competitions in a quarter (n)	3	6	6	2	4	4	3	6	6	2	4	4

the foot or touching the floor with a part of the body (stopwatch timer OFF). The participants attempted to hold the position for up to 1 min. The test result was the duration of continuously held balance, with a maximum score of 60 s.

Plate tapping test

The test was performed accordingly to the Eurofit testing battery [37]. The stand for the test comprised a table and plates placed on the table: one rectangular plate centrally located between two discus-shaped plates, 60 cm apart. Each subject, standing astride in front of the table as the starting position, placed the non-dominant hand on the rectangular plate, while the dominant hand was placed on the opposite plate. Then, that dominant hand touched each plate as quickly as possible, repeatedly touching them one by one. The subject performed 50 movements in total, i.e. each plate was being touched 25 times. The test result was the exact amount of time needed to touch each plate 25 times, measured with an accuracy of 0.1 s.

Jump Rope Test

The subject was in the starting straddle position, with legs spread out, holding the jump rope by the handles. The test lasted 30 s and consisted of jumping over the rope with both feet, while rotating the rope forward. The test result was the number of jumps in the given period of time.

Tennis skills tests

The two tennis skills tests began with the wall game test, followed by the 100-ball test. The former simulated the conditions during ball exchange during a tennis game, including mobility on the court, while the latter evaluated the precision of fundamental tennis strokes.

Wall Game Test

The test examines the degree of mastery of forehand and backhand strokes in terms of the technique (rhythm) of the strokes after the ball bounces once onto the court in a game against a wall. The subject stood behind the control line (6 m from the wall) with the ball in one hand and launched it into the game with a forehand stroke. As soon as the ball touched the wall, the investigator started the stopwatch and started to count the number of wall bounces. The duration of the test was 2 min. If the player crossed the control line (before or during the stroke) or hit the ball below the marked net, the stroke was not counted. In the event of an unsuccessful stroke, the subject launched another ball into the game. The test result was the number of correctly bounced balls off the wall.

100-tennis ball test

This test assesses the ability to control the ball through basic strokes (deep-court forehand and backhand, forehand volley, backhand half-court, and service). It consists of 100 strokes in 12 series, of which 80 strokes (deep-court forehand and backhand, forehand volley) are performed by a pass from the coach, and the remaining 20 are self-services performed with attention to the accuracy of each stroke. The subject stood behind the court baseline, in the middle, between the sidelines, waiting to hit a forehand. The coach was on the other side of the court, approximately 3–4 m from the net. A designated investigator, assessing the stroke accuracy and impact, was located behind the baseline on the coach's side. The coach started playing the balls with the racket in the order of attempts described below, starting with the forehand: Series I, ten diagonal strokes from the forehand; Series II, ten forehand strokes along the line; Series III, ten backhand strokes diagonally; Series IV, ten backhand strokes along the line; Series V, ten backhand volley strokes diagonally; Series VI, ten forehand volley strokes along the line; Series VII, ten backhand volley strokes diagonally; Series VIII, ten backhand volley strokes along the line; Series IX, five services in the inner zone of the right service penalty; Series X, five services in the outer zone of the right service penalty; Series XI, five services in the internal service penalty zone; Series XII, five services in the outer zone of the left service penalty. After completing the first series of 10 balls, without taking a break, the coach informed the subject about the change of the head-impact zone. After two series, a short break was used to collect the balls. After the first four series have been completed, the subject, located in the deep-court, stood in the centre of the court behind the service line and started the first series of volley strokes. After completing four series of volley, the subject moved to the main line of the court to perform four series of five serves.

Each stroke was assessed twice, once for accuracy (2 points for the primary control field, 1 point for the ball in the supplementary control field, 0 points for the ball out or in the net) and then for impact strength (2 points for the ball with a second hit outside of the line located 33 cm and 38 cm from the baseline, 1 point for no bounce on the surface between that line and the court line, and 0 points if the ball bounced before the court baseline). The sum of the points for accuracy and impact strength of 100 strokes gave the final test result of the entire test, with a maximum of 400 points.

Measures

Statistical analysis

Descriptive statistics, including mean and standard deviation (SD), were calculated for all measured variables. To assess the differences between measures at different time points (RM, repeated measure: Q1, Q2, Q3, Q4) and between sexes (GR: male, female), two-way ANOVA (4×2) with repeated measures was performed for specific age groups. To assess and compare the rate of development of motor coordination skills and tennis skills over 1 year (measured quarterly) between sexes (GR: male, female) and between age groups (age: 10, 11, 12 years), regression beta coefficient for each participant was calculated and then two-way ANOVA (2×3) was performed. For each ANOVA, the effect size was calculated by eta-squared statistics (η^2). Values equal to or greater than 0.01, 0.06, and 0.14 indicated a small, moderate, and large effect, respectively. Finally, Pearson correlation coefficient was calculated for particular motor coordination and tennis skills tests. All calculations were performed using Statistica 13 software (StatSoft, Tulsa, OK, USA). Differences were considered statistically significant when $p \leq 0.05$.

Results

The test results of 10-year-old children are shown in Fig. 1. ANOVA with repeated measures of motor coordination and tennis skills of 10-year-old male and female tennis players revealed a significant effect of the RM factor on all the tested indicators. A significant effect of the GR factor was noted, with boys performing better than girls in the Spalding test (5.37%, $\eta^2=0.38$, $p<0.01$), 100-ball test (9.29%, $\eta^2=0.18$, $p<0.01$), and wall game test (64.75%, $\eta^2=0.83$, $p<0.01$). Further, the results of Spalding test ($\eta^2=0.07$, $p<0.01$), Starosta's test ($\eta^2=0.05$, $p=0.04$), jump rope test ($\eta^2=0.05$, $p=0.02$), and wall game test ($\eta^2=0.05$, $p=0.03$) indicated a significant interaction of the GR × RM factors (Fig. 1C, F, J, K).

The test results of 11-year-old children are shown in Fig. 2. ANOVA revealed a significant effect of the RM factor on all the studied indicators, regardless of sex. A significant effect of the GR factor was noted, with boys performing better than girls in the plate tapping test (3.78%, $\eta^2=0.07$, $p=0.04$), Spalding test (8.79%, $\eta^2=0.40$, $p<0.01$), Spider test (3.75%, $\eta^2=0.13$, $p<0.01$), 100-ball test (10.66%, $\eta^2=0.07$, $p<0.01$), and wall game test (44.08%, $\eta^2=0.74$, $p<0.01$). A significant interaction of the GR × RM factors was evident in the complex reaction test (Fig. 2B, $\eta^2=0.08$, $p<0.01$), Starosta's test (Fig. 2F, $\eta^2=0.08$, $p<0.01$), 100-ball test (Fig. 2K, $\eta^2=0.05$, $p=0.04$), and wall game test (Fig. 2L, $\eta^2=0.05$, $p=0.03$).

The test results of 12-year-old children are shown in Fig. 3. As for the 10- and 11-year-olds, ANOVA revealed a significant effect of the RM factor in all performance tests. A significant effect of the GR factor was noted in the simple reaction test (0.92%, $\eta^2=0.07$ $p=0.04$), complex reaction test (5.88%, $\eta^2=0.07$, $p=0.03$), Spalding test (5.52%, $\eta^2=0.21$, $p<0.01$), Spider test (2.28%, $\eta^2=0.06$ $p<0.05$), Starosta's test (3.55%, $\eta^2=0.07$, $p=0.04$), plate

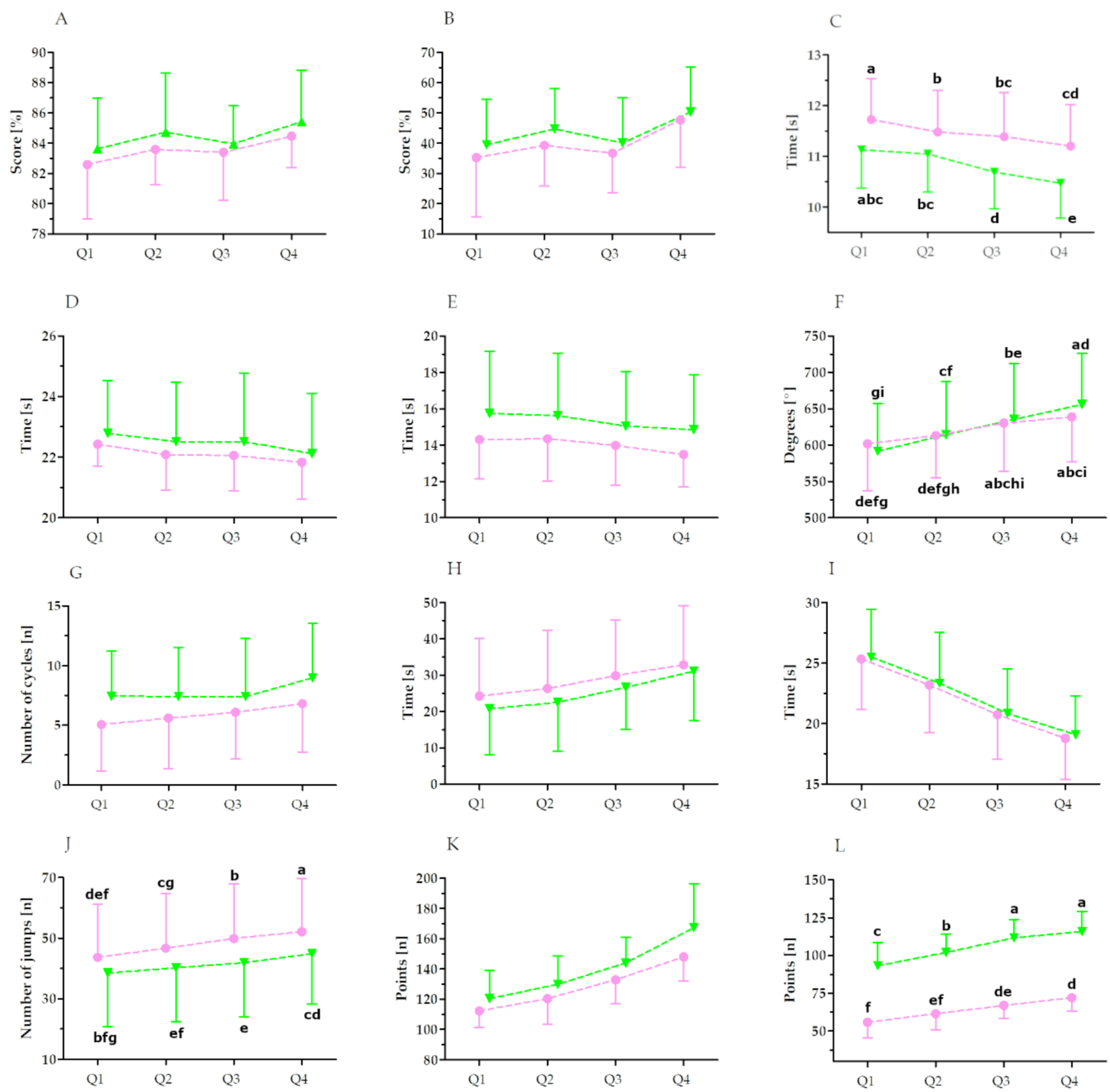

Fig. 1 Quarterly changes in performance of motor coordination tests and tennis skills tests in 10-year-old tennis players. Legends: (**A**, simple reaction; **B**, complex reaction; **C**, Spalding test; **D**, spider test; **E**, hexagon jumping; **F**, Starosta's test; **G**, hand–eye test; **H**, balance; **I**, plate tapping; **J**, jump rope), (**K**, wall game test; **L**, 100-tennis ball test), Note: Q1, Q2, Q3, and Q4 are quarters of the year, corresponding to measurements in March, June, September, and December, respectively. Different letters indicate significant differences. Pink, girls; Green, boys

tapping test (6.66%, η^2=0.08, p=0.03), 100-ball test (7.32%, η^2=0.07, p=0.04), and wall game test (28.44%, η^2=0.63, p<0.01), where boys performed significantly better than girls. However, in the hexagon jump test (5.40%, η^2=0.08, p=0.03), boys performed worse than girls. A significant interaction of the GR × RM factors was evident in the 100-ball test (Fig. 3K, η^2=0.06, p<0.01) and wall game test (Fig. 3L, η^2=0.07, p<0.01).

To evaluate the rate of 1-year development in the investigated age groups, differences in beta coefficients of linear regression were assessed (Table 3). A significant effect of the age factor was noted in the simple and complex reaction tests, spider test and the hand–eye and jump rope tests. The beta coefficient for the simple reaction test of 12-year-olds was 2.57- and 1.66-times higher than that of 10- and 11-year-olds, respectively. Similarly, for the complex reaction and hand–eye tests, the coefficient for 12-year-olds was 2.03- and 1.42-times higher than that for the youngest group, accordingly. In addition, in the former test, the beta coefficient for girls was

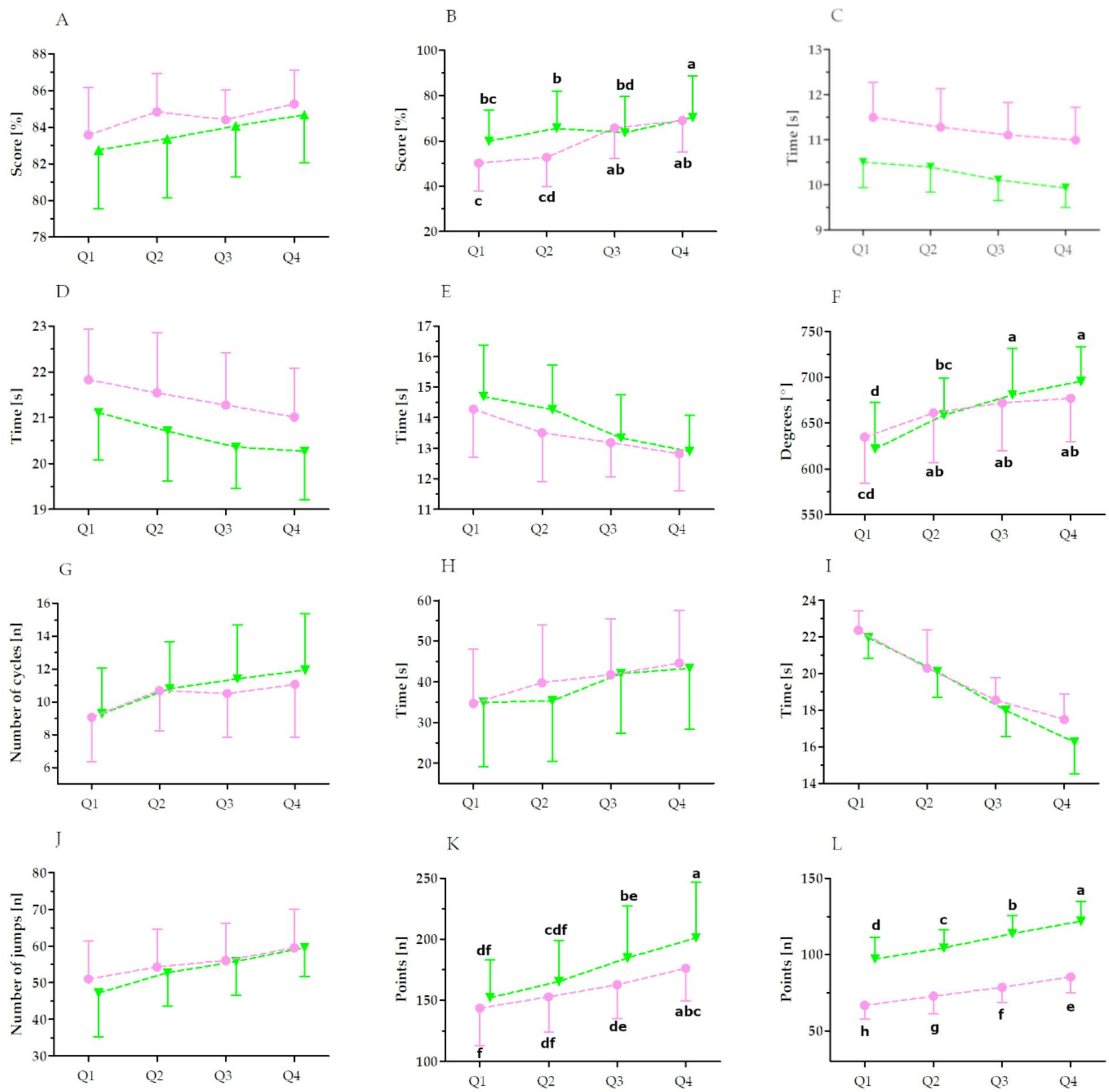

Fig. 2 Quarterly changes in performance of motor coordination tests and tennis skills tests in 11-year-old tennis players. Legends: (**A**, simple reaction; **B**, complex reaction; **C**, Spalding test; **D**, spider test; **E**, hexagon jumping; **F**, Starosta's test; **G**, hand–eye test; **H**, balance; **I**, plate tapping; **J**, jump rope), (**K**, wall game test; **L**, 100-tennis ball test). Note: Q1, Q2, Q3, and Q4 are quarters of the year, corresponding to measurements in March, June, September, and December, respectively. Different letters indicate significant differences. Pink, girls; Green, boys

45.65% higher than that for boys, regardless of the age group. For the plate tapping test, the beta coefficient for 10-year-olds was 11% higher than that for 12-year-olds, and negative in both groups. For the Spalding test, the beta coefficient for boys was 21% higher and negative, regardless of age. For the balance test, the beta coefficient for boys was 28.57% lower than that for girls. For the jump rope test, the beta coefficient for 10-year-olds was 17% higher than that for 12-year-olds, and that for boys was overall 13% higher than that for girls. However, as was shown by the interaction of GR × RM factors, the differences were mainly driven by the beta coefficient for 12-year-old girls being the lowest among the compared groups (Table 3). As a result of the interaction of both effects, the beta coefficient for the 100-ball test of 12-year-old girls was 17% higher than that of their male peers.

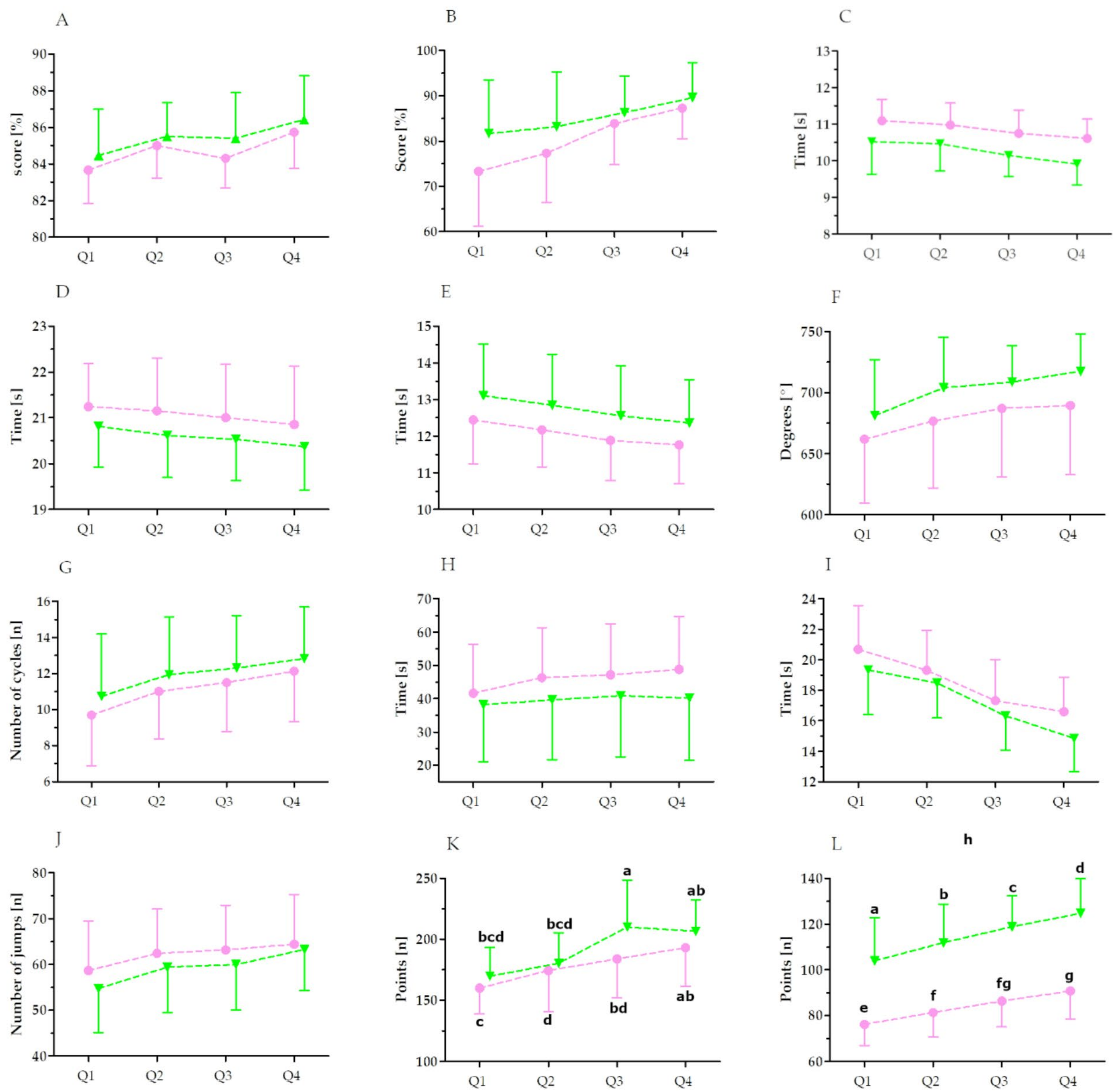

Fig. 3 Quarterly changes in performance of motor coordination tests and tennis skills tests in 12-year-old tennis players. Legends: (**A**, simple reaction; **B**, complex reaction; **C**, Spalding test; **D**, spider test; **E**, hexagon jumping; **F**, Starosta's test; **G**, hand–eye test; **H**, balance; **I**, plate tapping; **J**, jump rope), (**K**, wall game test; **L**, 100-tennis ball test). Note: Q1, Q2, Q3, and Q4 are quarters of the year, corresponding to measurements in March, June, September, and December, respectively. Different letters indicate significant differences. Pink, girls; Green, boys

Discussion

The aim of the current study was to assess 1-year development of motor coordination skills among 10–12-year-old male and female tennis players, in the light of changes in tennis-specific preparation. In the current study, for the first time, an attempt was made to answer the question of how motor coordination change in 10-, 11-, and 12-year-old girls and boys at quarterly intervals in the annual training cycle and whether there are significant sex-related differences. Significant quarterly changes in all motor coordination tests of all tennis players were noted, regardless of sex. Data analyses revealed the largest annual change (42.2%, $p<0.01$) among 10-year-old tennis players in the balance test performance. In turn, among 11- and 12-year-olds, the largest annual change in performance was observed in the 100-ball test and wall game test equal to 27.89% ($p<0.01$) and 21.50% ($p<0.01$), respectively. This shows that along with gaining tennis

Table 3 Two-way ANOVA (sex × age) of beta coefficients for linear regression analysis of quarterly changes in performance of motor coordination tests by 10–12-year-olds

Variable	Sex	10-year-olds (Mean ± SD)	11-year-olds (Mean ± SD)	12-year-olds (Mean ± SD)	Effect	*p*-value	Effect size (n^2)	Post-hoc outcome
Simple reaction test	B	0.19 ± 0.46	0.29 ± 0.49	0.55 ± 0.19	Age	< 0.01**	0.10	A12 > A10, A11
	G	0.25 ± 0.50	0.38 ± 0.41	0.56 ± 0.28	GR	0.45	< 0.01	
					Age × GR	0.92	< 0.01	
Complex reaction test	B	0.28 ± 0.39	0.39 ± 0.69	0.51 ± 0.67	Age	0.01*	0.05	A12 > A10
	G	0.35 ± 0.50	0.61 ± 0.60	0.77 ± 0.27	GR	0.03*	0.02	G > B
					Age × GR	0.62	0.01	
Spalding test	B	−0.91 ± 0.08	−0.84 ± 0.28	−0.68 ± 0.52	Age	0.06	0.03	B < G
	G	−0.75 ± 0.04	−0.63 ± 0.54	−0.61 ± 9.48	GR	0.02*	0.03	
					Age × GR	0.58	0.01	
Spider test	B	−0.46 ± 0.69	−0.74 ± 0.42	−0.69 ± 0.48	Age	0.03*	0.04	A10 > A11
	G	−0.54 ± 0.60	−0.77 ± 0.31	−0.61 ± 0.66	GR	0.65	< 0.01	
					Age × GR	0.27	0.01	
Hexagon jump test	B	−0.64 ± 0.51	−0.66 ± 0.47	−0.49 ± 0.55	Age	0.20	0.01	
	G	−0.71 ± 0.40	−0.65 ± 0.48	−0.56 ± 0.62	GR	0.60	< 0,01	
					Age × GR	0.88	< 0.01	
Starosta's test	B	0.80 ± 0.31	0.84 ± 0.20	0.58 ± 0.50	Age	0.11	0.02	
	G	0.79 ± 0.17	0.70 ± 0.36	0.51 ± 0.56	GR	0.17	0.01	
					Age × GR	0.12	0.02	
Hand–eye test	B	0.45 ± 0.58	0.79 ± 0.28	0.77 ± 0.35	Age	< 0.01**	0.06	A12 > A10
	G	0.65 ± 0.51	0.68 ± 0.42	0.81 ± 0.24	GR	0.47	< 0.01	
					Age × GR	0.15	0.02	
Balance test	B	0.60 ± 0.55	0.50 ± 0.52	0.29 ± 0.59	Age	0.11	0.02	G > B
	G	0.67 ± 0.50	0.70 ± 0.44	0.64 ± 0.47	GR	0.03*	0.03	
					Age × GR	0.56	< 0.01	
Plate tapping test	B	−0.97 ± 0.02	−0.96 ± 0.03	−0.86 ± 0.33	Age	0.01*	0.04	A11 < A12
	G	−0.98 ± 0.03	−0.93 ± 0.14	−0.86 ± 0.32	GR	0.95	< 0.01	
					Age × GR	0.71	< 0.01	
Jump rope test	B	0.82 ± 0.10	0.88 ± 0.14	0.81 ± 0.22	Age	0.02*	0.04	A10 > A12
	G	0.90 ± 0.22	0.74 ± 0.36	0.59 ± 0.52	GR	0.03*	0.02	B > G
					Age × GR	0.02*	0.04	G12 < B12, G10, B10, B11
Wall game test	B	0.87 ± 0.11	0.90 ± 0.69	0.90 ± 0.09	Age	0.37	0.01	
	G	0.88 ± 0.07	0.89 ± 0.60	0.88 ± 0.08	GR	0.65	< 0.01	
					Age × GR	0.38	0.01	
100-ball test	B	0.87 ± 0.10	0.85 ± 0.32	0.75 ± 0.21	Age	0.27	0.01	G12 > B12
	G	0.86 ± 0.08	0.75 ± 0.39	0.88 ± 0.10	GR	0.81	< 0.01	
					Age × GR	0.04	0.04	

Abbreviations: B, boys; G, girls; GR, sex; A10, 10 years old; A11, 11 years old; A12, 12 years old; G(10–12), girls of the specified age; B(10–12), boys of the specified age. Significant effect at *p < 0.05, **p < 0.01

expertise, the rate of tennis skill development is becoming more pronounced against the background of general motor coordination development. This is in line with periodization periods in young tennis players, where specific preparatory phase of training plays an increasingly important role starting from the age of 11 [18]. The main reasons for the improvement of motor coordination of the examined groups of girls and boys were a substantial amount of training dedicated to developing motor coordination during each training session on the court, and also changes resulting from biological development. It was previously shown that 11–14-year-old elite tennis players had better motor coordination than club-level tennis players [38], mostly as a result of a higher training volume.

The rate of 1-year developmental changes in simple and complex reaction times, hand–eye and plate tapping tests, measured by the beta coefficient, was highest in 12-year-old players. This indicates that fast-paced manual tasks are most susceptible to training later in the tennis training process. This could be explained by the maturation of the nervous system, wherein both, the myelination process and increasing axon diameter [39, 40] provide faster neuromuscular communication [41].

In a previous study, Kramer et al. [9] investigated 3-year changes in, among others, agility using the spider test, among 14–16-year-old tennis players. Overall, the 14–16-year-olds performed better than our participants who were younger (10–12 years old). However, the performance improvement over 1 years was more rapid in 10–12-year-olds than that in 14–16-year-olds, both boys (10% vs. 5.3%) and girls (7% vs. 2.5%). This indicates that the importance of development of unspecific agility performance declines or reaches an optimal level at 14-16-year-olds. This was supported by our observations with 10-year-old tennis players who showed the most rapid 1-year development of this skill, based on the beta coefficient of linear regression of quarterly changes. It should be pointed out that in the current study, measurements over 1 years consecutive years were derived from different participants, while in Kramer et al. [9], the longitudinal study was conducted in the same group.

We hypothesized that rate of 1-year development of motor coordination skills will be higher in younger groups. As it was observed, the rate of development was associated more with particular tests rather than age. Moreover, while the tennis skills development was the highest in 12-year-olds, there were no significant difference with younger groups. Thus hypothesis of increasing rate of 1-year tennis skills development with age could not be confirmed as well.

In the overall European population, except for the balance, plate tapping, and sit-and-reach tests, the physical fitness of 10–12-year-old boys measured by the Eurofit test is better than that of peers [42]. In the current study, regardless of the repeated quarterly measurement, the Spalding, 100-ball, and wall game test results of 10-, 11-, and 12-year-old boys were significantly better than those of girls. In addition, 11 and 12-year-old male tennis players performed significantly better in the Spider test and plate tapping test than female tennis players. Considering the plate tapping test, it was shown that in the European population, until the age of 12, girls perform better than boys but the advantage of boys then increases, year upon year. In relation to that, the current study suggests that tennis training probably accelerates the typical development of this motor coordination skill among boys by approximately 1 year. This is in accordance with another study, which reported a better plate taping performance of 10–12 years male tennis players [43]. Of note, among 12–13-year-olds, tennis players as well as untrained peers, the tapping test performance decreased over the time period of 1992–2008; however, it is difficult to compare that to the outcomes of the current study, as we used the Eurofit test instead of counting the number of taps in 20 s [44]. The populational sex difference was also apparent with respect to the balance skills, with the girls performing slightly better across 10–12-year-olds and even older adolescents [42]. The same was observed here and was comparable to the finding of another study [43], yet the difference between boys and girls did not reach statistical significance. Finally, girls exhibited faster rate of 1-year development than boys, regardless of the age group, which confirms our second hypothesis that female tennis players will exhibit different rate of development than males when it concerns balance related skills.

The Spalding and spider tests are used for agility evaluation, wherein the former incorporates a short (8–10 m) sprinting section and is similar to the Eurofit's 10×5 m shuttle run. Overall, the reported agility test performance of 10–12-year-old boys is better than that of girls [42]. The same outcome was observed in the current study; however, in the spider test, only 11- and 12-year-old boys performed better than girls. Better agility test performance among young male tennis players has also been reported in other studies [9, 45–48]. This observation could be explained by the nature of the spider test which, in comparison to other agility tests, also incorporates in the assessment the dexterity aspect of grabbing and placing the tennis ball on the designated spot (tennis racket): as mentioned above, 10-year-old female tennis players perform fast-paced dexterity tasks (plate taping test) better than 10-year-old male tennis players. Further, the rate of 1-year developmental changes in the Spalding test performance of male tennis players was higher than that of girls, regardless of the age group.

In the current study, 12-year-old female tennis players performed better than boys of the same age in only one motor coordination test, i.e. the hexagon jump test. This was similar to the findings of Roetert et al. [45], and was also reported for 14-year-old tennis players [47]. By contrast, Myburgh et al. [49] reported no sex-associated differences among 10–12-year-old elite tennis players performing the hexagon jump test. It appears that the performance of repeated jumping tasks by young female tennis players was slightly better because of better jumping precision, as they scored less errors during the hexagon jump test than boys. This was also apparent in the jump rope test, wherein 10-year-old female tennis players performed better than boys. Similar was observed among the 12-year-olds, but the difference with boys did not reach statistical significance. Analysis of the beta coefficients of 1-year quarterly changes in the performance of jump rope test revealed that the rate of development was the lowest among 12-year-old female tennis players, probably because they have achieved an optimal potential earlier than other groups.

In the current study, the 12-year-old male tennis players also performed better than girls in the simple and complex reaction tests, and in the Starosta's test. It was previously shown that the simple reaction time of boys is better than that of girls, with the major improvement in this skill between the ages of 9 and 11 [50, 51]. However, Lynn and Ja-Song [52] pointed out that that is true only in terms of the movement speed not the decision time. For the Starosta's test, data on children and adolescents are lacking; however, young untrained male adults also perform better than females [53]. Interestingly, while

12-year-old female tennis players performed relatively worse in the complex reaction test, they showed higher 1-year rate of development of complex reaction performance, regardless of the age group. This suggests that girls were catching up with the development level of this particular motor coordination skill that boys have achieved earlier.

Furthermore, the 10–12-year-old male tennis players performed better in many of the investigated motor coordination tests (e.g. 6/10 tests in the case of 12-year-old boys), and were also more skilled in terms of tennis skills tests: the 100-ball and wall game tests. These findings are in opposition to those of Theodoros et al. [54], who reported no difference between male and female tennis players in terms of the accuracy of backhand, forehand, and service strokes. This could be explained by the notion that the 100-ball test equally evaluates the accuracy and impact strength, and male tennis players exhibit higher muscle strength and, as a result, higher acceleration of the tennis ball, than female tennis players [42, 55, 56]. The quarterly change analysis revealed that among 12-year-olds, girls exhibited a higher rate of technical skill development in the 100-ball test than boys. To an extent, this could be explained by some maturation processes that take place earlier in girls than in boys. Nonetheless, their performance was much worse than that of 12-year-old male tennis players. It should be also noted that the observed sex-associated differences in the developmental changes in the motor coordination and tennis skills of tennis players occurred while boys and girls were following the same sports training program in tennis and physical education. Presented outcome shows clearly, that over subsequent years in 10–12-year-old male tennis players the advantage in motor coordination and tennis skills performance over female tennis players increases. This confirms the regulations of the International Tennis Federation along with Polish Tennis Association, that does not allow competition between 11-years-old and older girls and boys on tennis court.

One of the limitations of the current study is that we did not control for the children's maturity status and, hence, some of the outcome could be influenced by puberty, especially among girls. However, based on the analysis of physical characteristics of the investigated age groups, no differences in stature or body mass were apparent between boys and girls in any particular age group. Therefore, their puberty status was similar and the impact of physical development should have been comparable in both sexes. Another limitation is related to study design. The current study investigated 1-year changes in three age groups instead of 3-year longitudinal study. While this approach hinders and limits inference as a whole 3-year period [57], it allows to maintain similar conditions for each of age group during 1-year period as they were investigated at the same time. Thus, current method suits more the study's aim. Nevertheless, more longitudinal studies are needed, that will investigate the long-term developmental changes in young tennis players and confront the outcome of the presented study. This will allow to understand more the differences in motor coordination development, especially if it would be in association with tennis competitive performance.

Conclusions

The current study revealed that 1-year development of motor coordination and tennis skill is age-, sex-, and task-dependent. In terms of tennis skills, the performance of 10–12-year-old male tennis players was better than that of females. Overall, 10–12-year-old male tennis players in each subsequent age category showed to have better motor coordination than girls. The presented findings give insight into the motor coordination development of 10–12-year-old tennis players, which may be useful for coaches and instructors in adjusting training programs according to age and sex of young tennis players.

Abbreviations

SD	Standard deviation
ANOVA	Analysis of variance
RM	Repeated measure
GR	Sexes

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s13102-024-00978-3.

Supplementary Material 1

Acknowledgements
Not applicable.

Author contributions
Conception and design of the study: T.W., A.D. and A.K. Data acquisition, analysis or interpretation of data: T.W., E.W., A.D., B.N., J.M., A.K. Drafting the manuscript: T.W., A.D., B.N., J.M., A.K. All authors critically reviewed the manuscript for important intellectual content and approved the final version.

Funding
No specific grant funding was received for this study.

Data availability
Data are available upon reasonable request from the corresponding author.

Declarations

Ethics approval and consent to participate
The study was conducted in accordance with the Declaration of Helsinki and approved by the Bioethics Committee at Gdansk (KB-25/20). Legal guardians of all participants provided informed written consent to participate in the study prior to the study.

Consent for publication
Not applicable.

Competing interests

The authors declare no competing interests.

Received: 20 February 2024 / Accepted: 2 September 2024
Published online: 11 September 2024

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