International Journal of Sports Physiology and Performance, 2016, 11, 793-801
http://dx.doi.org/10.1123/ijspp.2015-0141

Human Kinetics
ORIGINAL INVESTIGATION

Do Running Activities of Adolescent and Adult Tennis Players Differ During Play?

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Purpose: To investigate differences in running activities between adolescent and adult tennis players during match play. Differences between winning and losing players within each age group were also examined. ***Methods:*** Forty well-trained male players (20 adolescents, 13 ± 1 y; 20 adults, 25 ± 4 y) played a simulated singles match against an opponent of similar age and ability. Running activities were assessed using portable devices that sampled global positioning system (10 Hz) and inertial-sensor (accelerometer, gyroscope, and magnetometer; 100 Hz) data. Recorded data were examined in terms of velocity, acceleration, deceleration, metabolic power, PlayerLoad, and number of accelerations toward the net and the forehand and backhand corners. ***Results:*** Adult players spent more time at high velocity (≥4 m/s^2), acceleration (≥4 m/s^2), deceleration (≤–4 m/s^2), and metabolic power (≥20 W/kg) ($P \leq .009$, ES = 0.9–1.5) and performed more accelerations (≥2 m/s^2) toward the backhand corner ($P < .001$, ES = 2.6–2.7). No differences between adolescent winning and losing players were evident overall ($P \geq .198$, ES = 0.0–0.6). Adult winning players performed more accelerations (2 to <4 m/s^2) toward the forehand corner ($P = .026$, ES = 1.2), whereas adult losing players completed more accelerations (≥2 m/s^2) toward the backhand corner ($P \leq .042$, ES = 0.9). ***Conclusion:*** This study shows that differences in running activities between adolescent and adult tennis players exist in high-intensity measures during simulated match play. Furthermore, differences between adolescent and adult players, and also between adult winning and losing players, are present in terms of movement directions. Our findings may be helpful for coaches to design different training drills for both age groups of players.

Keywords: energy expenditure, GPS, inertial movement analysis, microsensor technology, speed

Tennis match play involves repeated high-intensity activities (ie, ~5–10 s) separated by recovery intervals of defined durations (ie, 10–20 s between points, 90 s during changeovers, and 120 s between sets) over a period of time that is not predictable (ie, ~1.5–6.0 h).[1,2] Over the past 2 decades, tennis has evolved into a highly demanding sport in all age groups.[2–4] Keeping pace with this progress requires specific training drills, for which knowledge concerning mechanical loads and physiological responses of players during match play is essential.[5] While physiological responses are well investigated,[1–3] data concerning mechanical loads are limited.[4] One major explanation for the latter may be that no appropriate technologies to determine mechanical loads were available in the past.[6]

Over the past 5 years, portable devices incorporating global positioning system (GPS) and inertial-sensor (ie, accelerometers, gyroscopes, and magnetometers) technologies[7] have been frequently used to examine mechanical loads with respect to running activities in different intermittent sports, mainly Australian football, rugby league and union, cricket, hockey, and soccer.[8] However, to optimize training drills based on the application of these technologies, an understanding of different methodological approaches to analyze the collected data is necessary.

In this context, GPS data are sampled at 1 to 15 Hz[9] and are used to calculate running velocities, which are traditionally expressed as distance covered, time spent, or frequency in different velocity categories.[10] For intermittent sports such as tennis, this approach is potentially inadequate because maximally performed changes in running velocities and directions over short distances are misinterpreted as low to moderate intensities because the attained velocities are not high.[11,12] For this reason, few studies have used changes in running velocity to calculate associated acceleration and deceleration data,[13,14] allowing an analysis of intermittent running activities, which is more appropriate than traditional approaches that use only velocity data.[4,11] A recent approach has continued the demonstrated progress by using all velocity, acceleration, and deceleration data to predict the instantaneous energy expenditure, energy cost, and metabolic power of intermittent running.[15,16] This recent approach is promising because new insight into the mechanics and energetics of intermittent running activities is provided.[17,18]

In addition to running, mechanical loads of intermittent sports involve other activities such as jumps (eg, split steps in tennis) that cannot be quantified by GPS data.[7,12] Consequently, 100-Hz triaxial accelerometers, gyroscopes, and magnetometers were also integrated into GPS devices to determine total mechanical loads more accurately.[19] The most common accelerometer-derived parameter is PlayerLoad,[20] which is a vector magnitude and is calculated from changes in accelerations measured in all 3 movement planes.[19] One limitation of PlayerLoad is that changes in all acceleration directions are considered universally. An enhanced approach using accelerometer data is inertial-movement analysis. This approach combines accelerometer with gyroscope and magnetometer data, allowing the examination of accelerations with respect to movement directions.[19]

In tennis, it is known that fitness levels[21,22] and activity profiles during match play (eg, number of strokes per rally)[23,24] differ between adolescent and adult players. Therefore, it is reasonable to expect that running activities between both groups also differ during play. Success in tennis is multifactorially determined,[3,25] but it is

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accepted that stroking skills are key factors.[26,27] However, running is a fundamental requirement to participate in tennis play.[4] Because it has recently been reported in top players that losers of a rally covered 10% more distance than winners,[28] it could be hypothesized that differences exist in running activities between winning and losing players during match play. Generally, there have been few studies[29–31] that have investigated running activities during tennis match play. Because all previous studies focused solely on global (eg, distances covered)[29,31] or potentially inadequate high-intensity (eg, times spent in different velocity categories)[30] indicators, it is worth examining running activities during match play using, for tennis, new technologies[6] and more appropriate data-processing procedures.[13–16,19] Such knowledge may help coaches optimize training drills for the players.[5]

The purpose of this study was to investigate differences in running activities between adolescent and adult tennis players during match play. Differences between winning and losing players within each age group were also examined.

Methods

Participants

Forty well-trained male tennis players (20 adolescents, 20 adults) participated. All players trained on court 2 to 4 times per week, were right-handed, and preferred a balanced combination of baseline play and attacking toward the net. Adult players were regionally ranked ≤5, where 1 indicated the highest ranking and 23 the lowest. All players, and also the parents of adolescents, provided written consent, and the study was approved by the ethics committee of the local university. Table 1 summarizes the anthropometric characteristics and tennis backgrounds of the players.

Study Design

During the first 2 weeks after completing the outdoor season, players were asked to play a simulated tennis singles match against an opponent of similar age and ability, as decided by professional coaches who were familiar with the players. Players were instructed to report to the match well rested and to refrain from strenuous exercise for 48 hours beforehand. Players were also asked to prepare themselves as they would for a competition. Matches were played outdoors on red-clay courts according to the rules of the International Tennis Federation and involved 2 sets. If necessary, a final tiebreaker, in which the first player to receive 10 points would win, was played as a third set. Playing durations in adolescent and adult players were 81 ± 15 versus 84 ± 17 minutes, respectively, and did not differ (P = .599, ES = 0.2). Before the matches, players warmed up for 10 minutes with groundstrokes, volleys, overheads, and serves. Three new balls (Dunlop, Fort Tournament, Blackpool, UK) were used for each match. During play, players retrieved their own balls and counted games won, and they were allowed to drink water ad libitum. Weather conditions during all matches were ambient temperature 18–26°C and 36–44% humidity.

Data Collection

Running activities during simulated tennis match play were assessed with portable devices that sampled GPS and inertial-sensor data at 10 and 100 Hz, respectively (Catapult Innovations, MinimaxX S4, Melbourne, Australia). For these devices, an acceptable validity and reliability for measuring GPS[9,32] and inertial-sensor data[20,33] was provided. Devices were worn beneath the players' attire in custom-made neoprene harnesses located between the scapulae. To obtain clear satellite signals, devices were activated 15 minutes before data collection, and matches were played under cloudless skies. During play, devices had connections with 12.6 ± 1.0 satellites and the horizontal dilution of position was 1.0 ± 0.1, indicating ideal measuring conditions.[34]

Data Processing

Proprietary software (Catapult Innovations, Sprint 5.1.4, Melbourne, Australia) provided GPS raw velocity data, which were passed through a Butterworth filter to eliminate noise.[4] A filtering frequency of 1 Hz was applied because pilot testing in well-trained players revealed that this frequency yielded the highest reliability for velocity data over baseline shuttle sprints (CV ≤ 4.7%).[4] Filtered velocity data were exported to a spreadsheet (Microsoft, Excel 2013, Redmond, WA, USA), which calculated distances covered, mean and peak velocities, and times spent in 5 velocity categories: 0 to <1, 1 to <2, 2 to <3, 3 to <4, and ≥4 m/s.[4] From changes in velocities, associated acceleration and deceleration data were computed and analyzed as time spent in the following categories: 2 to <4, ≥4, –2 to >–4, and ≤–4 m/s².[4,14] Based on velocity, acceleration, and deceleration data, the spreadsheet calculated energy expenditures (kJ/kg), mean and peak metabolic power (W/kg), and time spent in 5 metabolic-power categories: 0 to <10, 10 to <20, 20 to <35, 35 to <55, and ≥55 W/kg.[17,18]

Inertial-sensor data were investigated using proprietary software (Catapult Innovations, Sprint 5.1.4). From the accelerometer data, PlayerLoads (ie, the root of the sum of squared changes in anteroposterior, mediolateral, and vertical accelerations)[19] were determined and expressed as arbitrary units (AU). Next, accelerometer data were examined with a Kalman filter to compute non-gravity-affected forward accelerations.[19] Based on those calculations and combined with gyroscope and magnetometer data, the software provided the number of accelerations and corresponding movement directions with respect to ±180° in the horizontal plane. To simplify, the accelerations were studied applying the same categories used for analyses of GPS acceleration data (ie, 2–<4 and ≥4 m/s²), and directions were classified into 3 movement categories: –45° to +45°, <–45° to >–135°, and >+45° to <+135°. We assumed that accelerations with a horizontal angle at 0° were performed frontally toward the tennis net. Consequently, in our right-handed players, accelerations in the 3 movement categories were defined as conducted toward the net, backhand corner, and forehand corner, respectively.

Statistical Analyses

Because Kolmogorov-Smirnov tests revealed that all data were distributed normally, parametric statistical calculations were applied. Descriptive statistics were reported as mean values, standard deviations (SD), and percentage differences. While differences between adolescent and adult players were examined with a 2-tailed t-test for independent samples, differences between winning and losing players within each age group were investigated with a 2-tailed t-test for dependent samples, because both data sets were linked by the matches played. Statistical significance was set at $P < .05$. For interpretation of the meaningfulness of differences, effect sizes (ES) according to Cohen d were calculated and interpreted as 0.2 to <0.6, small; 0.6 to <1.2, medium; 1.2 to <2.0, large; 2.0 to <4.0, very large; and ≥4.0, extremely large.[35] SPSS software (IBM, Version 22, Armonk, New York, USA) was used for all statistical calculations.

Table 1 Differences in Anthropometric Characteristics, Tennis Backgrounds, and Running Activities During Simulated Match Play Between Adolescent and Adult Tennis Players, Mean ± SD

Variable	Adolescent players (n = 20)	Adult players (n = 20)	Diff (%)[a]	*P*	ES
Anthropometric characteristics					
age (y)	13 ± 1	25 ± 4	+92.3	<.001	3.8
body height (cm)	160 ± 14	185 ± 7	+15.6	<.000	2.3
body mass (kg)	49 ± 12	80 ± 9	+63.3	<.001	3.0
body-mass index (kg/m^2)	19 ± 2	23 ± 2	+21.1	<.001	2.3
Tennis background					
tennis experience (y)	6 ± 2	18 ± 4	+200.0	<.001	3.9
training sessions/wk	3 ± 1	3 ± 1	0.0	.549	0.2
tournaments/season[b]	8 ± 2	17 ± 7	+112.5	<.001	1.9
ranking	n/a	3 ± 2	n/a	n/a	n/a
Velocity					
distance covered (m)	3477 ± 889	3244 ± 894	–6.7	.415	0.3
mean velocity (m/s)	0.7 ± 0.1	0.6 ± 0.1	–14.3	.026	0.7
peak velocity (m/s)	4.3 ± 0.5	5.5 ± 1.4	+27.9	<.001	1.1
0 to <1 m/s (s)	3331 ± 466	3614 ± 671	+8.5	.014	0.5
1 to <2 m/s (s)	1404 ± 389	1307 ± 518	–6.9	.509	0.2
2 to <3 m/s (s)	113 ± 54	86 ± 44	–23.9	.085	0.6
3 to <4 m/s (s)	21 ± 11	19 ± 12	–9.5	.595	0.2
≥4 m/s (s)	3 ± 3	8 ± 7	+166.7	.005	1.0
Acceleration					
2 to <4 m/s^2 (s)	59 ± 13	62 ± 21	+5.1	.719	0.1
≥4 m/s^2 (s)	19 ± 18	42 ± 32	+121.1	.008	0.9
Deceleration					
–2 to >–4 m/s^2 (s)	48 ± 17	38 ± 14	–20.8	.070	0.6
≤–4 m/s^2 (s)	5 ± 2	10 ± 4	+100.0	<.001	1.6
Metabolic power					
energy expenditure (kJ/kg)	15.9 ± 4.2	14.7 ± 4.7	–7.5	.442	0.3
mean metabolic power (W/kg)	3.2 ± 0.4	2.9 ± 0.5	–9.4	.025	0.7
peak metabolic power (W/kg)	81.2 ± 22.6	124.5 ± 32.9	+53.3	<.001	1.5
0 to <10 W/kg (s)	4712 ± 771	4872 ± 816	+3.4	.526	0.2
10 to <20 W/kg (s)	128 ± 51	113 ± 56	–11.7	.379	0.3
20 to <35 W/kg (s)	25 ± 10	37 ± 15	+48.0	.006	0.9
35 to <55 W/kg (s)	6 ± 3	9 ± 4	+50.0	.003	1.0
≥55 W/kg (s)	1 ± 1	3 ± 2	+200.0	.009	0.9

[a] Difference calculated from the perspective of adult players. [b] Season is from May to July.

Results

Differences Between Adolescent and Adult Players

Table 1 shows that adult players were older, taller, and heavier and had higher body-mass indexes ($P < .001$, ES = 2.3–3.8). While both groups performed the same number of training sessions per week ($P = .549$, ES = 0.2), adult players had more tennis experience and played more tournaments per season ($P < .001$, ES = 1.9–3.9). Table 1 shows that both groups covered comparable distances ($P = .415$, ES = 0.3), whereas adult players reached higher peak velocities ($P < .001$, ES = 1.1) and spent more times in velocity categories 0 to <1 and ≥4 m/s ($P \le .014$, ES = 0.5–1.0). Adult players also spent more time in the acceleration and deceleration categories ≥4 and ≤–4 m/s^2 ($P \le .008$, ES = 0.9–1.6). While both groups had comparable energy expenditures ($P = .442$, ES = 0.3), adult players reached higher peak metabolic power ($P < .001$, ES = 1.5) and spent more time in metabolic-power categories ≥20 W/kg ($P \leq .009$, ES = 0.9–1.0). Nevertheless, adult players had lower mean metabolic power and velocity ($P \leq .026$, ES = 0.7). Figure 1(A) shows that PlayerLoads in adolescent and adult players were 407 ± 130 versus 379 ± 91 AU, respectively, and did not vary ($P = .438$, ES = 0.2). Figures 2(A) and 2(B) show that adult players performed more accelerations in categories 2 to <4 and ≥4 m/s^2 toward the backhand corner ($P < .001$, ES = 2.6–2.7). Corresponding numbers of accelerations in category 2 to <4 m/s^2 toward the net and the backhand and forehand corners in adolescent and adult players were 66 ± 28 versus 67 ± 28, 87 ± 30 versus 196 ± 52, and 81 ± 37 versus 100 ± 33, respectively. Corresponding numbers of accelerations in category ≥4 m/s^2 were 29 ± 26 versus 45 ± 33, 8 ± 3 versus 34 ± 13, and 19 ± 18 versus 15 ± 19, respectively.

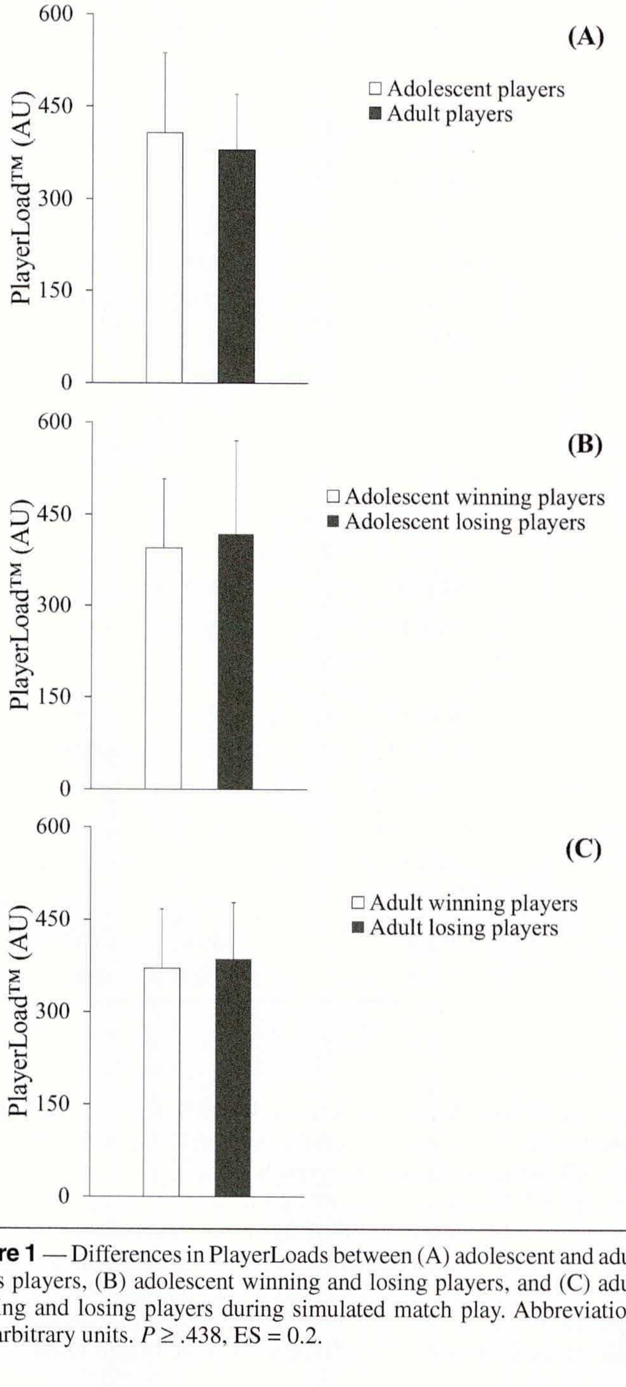

Figure 1 — Differences in PlayerLoads between (A) adolescent and adult tennis players, (B) adolescent winning and losing players, and (C) adult winning and losing players during simulated match play. Abbreviation: AU, arbitrary units. $P \geq .438$, ES = 0.2.

Differences Between Adolescent Winning and Losing Players

Table 2 shows that anthropometric characteristics, tennis background, and running activity of adolescent winning and losing players were comparable ($P \geq .198$, ES = 0.0–0.6). Figure 1(B) shows that PlayerLoads in adolescent winning and losing players were 395 ± 112 versus 418 ± 152 AU, respectively, and did not differ ($P = .674$, ES = 0.2). Figures 2(C) and 2(D) show that adolescent winning and losing players performed comparable numbers of accelerations in categories 2 to <4 and ≥4 m/s^2 toward the net and the backhand and forehand corners ($P \geq .204$, ES = 0.1–0.6). Corresponding numbers of accelerations in category 2 to <4 m/s^2 toward the net and the backhand and forehand corners in adolescent winning and losing players were 64 ± 32 versus 67 ± 26, 84 ± 28 versus 91 ± 33, and 77 ± 27 versus 85 ± 46, respectively. Corresponding numbers of accelerations in category ≥4 m/s^2 were 25 ± 29 versus 33 ± 25, 7 ± 3 versus 8 ± 3, and 14 ± 10 versus 24 ± 23, respectively.

Differences Between Adult Winning and Losing Players

Table 3 shows that anthropometric characteristics and tennis background, and also running activity with the exception of movement direction (ie, from a general physical perspective), of adult winning and losing players were comparable ($P \geq .211$, ES = 0.0–0.6). Figure 1(C) shows that PlayerLoads in adult winning and losing players were 372 ± 96 versus 389 ± 91 AU, respectively, and did not vary ($P = .663$, ES = 0.2). However, Figure 2(E) shows that adult winning players performed more accelerations in category 2 to <4 m/s^2 toward the forehand corner ($P = .026$, ES = 1.2). Figure 2(E) and 2(F) also show that adult losing players performed more accelerations in categories 2 to <4 and ≥4 m/s^2 toward the backhand corner ($P \leq .042$, ES = 0.9). Corresponding numbers of accelerations in category 2 to <4 m/s^2 toward the net and the backhand and forehand corners in adult winning and losing players were 62 ± 19 versus 72 ± 35, 175 ± 47 versus 218 ± 49, and 118 ± 32 versus 83 ± 25, respectively. Corresponding numbers of accelerations in category ≥4 m/s^2 were 37 ± 26 versus 53 ± 28, 28 ± 13 versus 39 ± 12, and 21 ± 25 versus 9 ± 7, respectively.

Discussion

This study was the first to investigate differences in running activity between adolescent and adult tennis players and also between winning and losing players within each age group during simulated match play. Our major findings were that differences in running activity between adolescent and adult tennis players were found at higher velocities, accelerations, decelerations, and metabolic power and also with respect to the number of accelerations toward the backhand corner, and no differences between adolescent winning and losing players were evident overall. However, differences between adult winning and losing players were detected with regard to the number of accelerations toward the backhand and forehand corners.

The results of the current study could not be compared with those of previous studies[29–31] because different methodological approaches were applied. However, to review previous studies for the readers, Christmass et al[29] determined the number of steps performed during 90 minutes of simulated tennis play in state-level players and reported values between 1.0 and 1.3 steps/s of rally. Murias et al[31] compared the distances covered on clay and hard

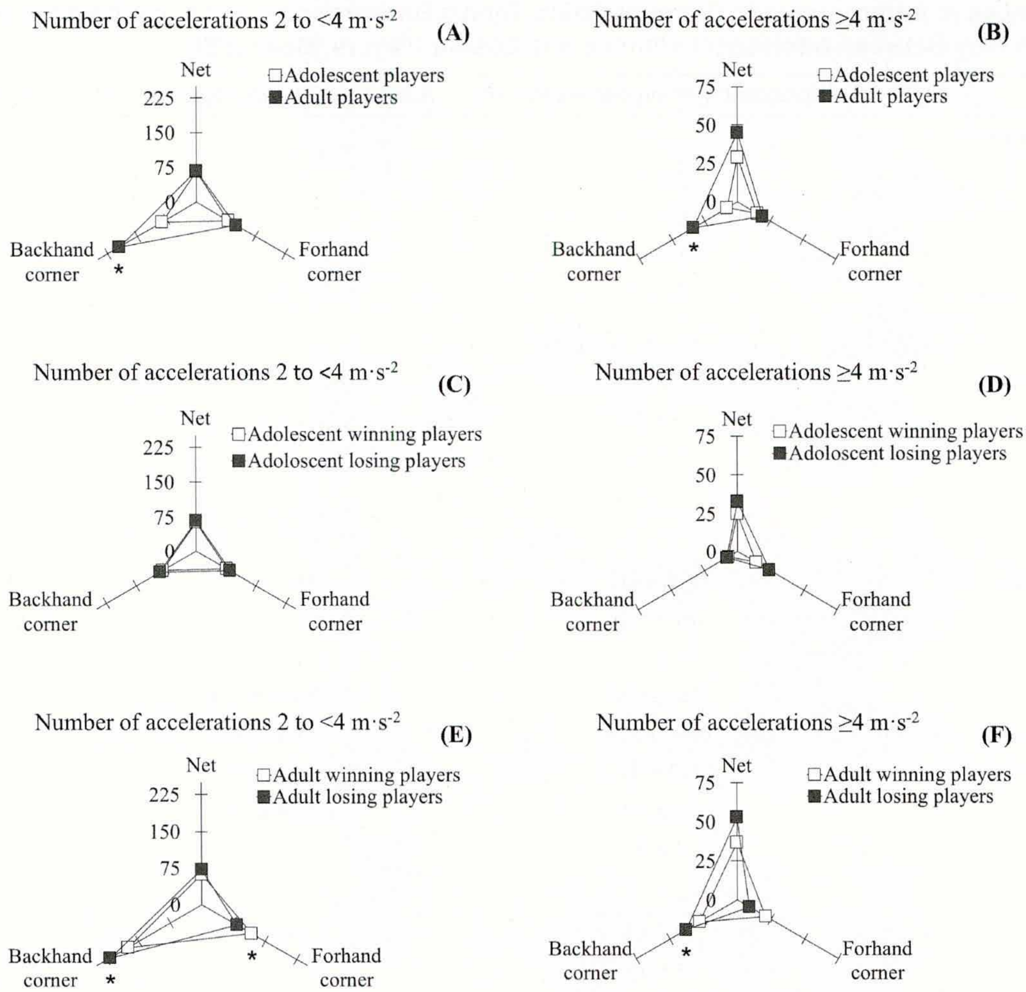

Figure 2 — Differences in numbers of accelerations toward the net and the backhand and forehand corners between (A and B) adolescent and adult tennis players, (C and D) adolescent winning and losing players, and (E and F) adult winning and losing players during simulated match play. $*P \leq .042$, ES = 0.9–2.7.

courts during a 90-minute simulated match and demonstrated that regionally ranked players ran farther on clay than on hard courts (1447 vs 1199 m) when the ball was in play. Fernandez-Fernandez et al[30] investigated the distances covered and times spent in different velocity categories during 60 minutes of simulated play in advanced and recreational veteran players and found that advanced players covered more distance (3569 vs 3174 m), whereas recreational players spent more time in higher velocity categories (eg, 18 to <24 km/h: 25 vs 73 s). Compared with previous studies, our study provides more detailed insights into running activities in tennis regarding global (eg, distance covered and energy expenditures) and high-intensity (eg, time spent in velocity, acceleration, deceleration, and metabolic-power categories) measures, and also with respect to movement directions (eg, number of accelerations toward the backhand and forehand corners), which may help coaches design more specific training drills for their players.

The first major finding was that differences in running activity between adolescent and adult players were found at higher velocities, accelerations, decelerations, and metabolic powers (Table 1) and also in the number of accelerations toward the backhand corner (Figure 2[A] and 2[B]). Adult players reached higher peak velocities and spent more time in velocity categories 0 to <1 and ≥4 m/s. These findings indicate that adult players had more and larger changes in running velocity than adolescent players. In fact, acceleration and deceleration data revealed that adult players spent more time in categories ≥4 and ≤–4 m/s^2. Plausibly, adult players also reached higher peak metabolic power and spent more time in metabolic-power categories ≥20 W/kg, because all velocity, acceleration, and deceleration data had provided the basis for our metabolic-power calculations.[15,16] In addition to these differences, the current study shows that adult players performed more accelerations toward the backhand corner. Our outcomes demonstrate that differences in running activity between adolescent and adult players were evident with respect not only to high-intensity-running indices but also to movement directions. The underlying reasons for all these differences remain hypothetical. Nevertheless, it has been sufficiently documented in the literature that fitness,[21,22] technical-tactical skill[23,27] levels, and, consequently, activity profiles[23,24] vary between adolescent and adult players, which may contribute to the differences in running activity during simulated match play detected in this study.

Another noteworthy finding was that no differences in running activity between adolescent winning and losing players were evident overall (Table 2, Figures 1[B], 2[C], and 2[D]). This finding

Table 2 Differences in Anthropometric Characteristics, Tennis Backgrounds, and Running Activities During Simulated Match Play Between Adolescent Winning and Losing Players, Mean ± SD

Variable	Adolescent winning players (n = 10)	Adolescent losing players (n = 10)	Diff (%)[a]	*P*	ES
Anthropometric characteristics					
age (y)	13 ± 1	13 ± 1	0.0	.468	0.4
body height (cm)	162 ± 14	159 ± 13	−1.9	.598	0.3
body mass (kg)	50 ± 14	47 ± 9	−6.0	.659	0.2
body-mass index (kg/m^2)	18 ± 2	19 ± 2	+5.6	.451	0.3
Tennis background					
tennis experience (y)	6 ± 2	7 ± 2	+16.7	.678	0.1
training sessions/wk	3 ± 1	3 ± 1	0.0	1.000	0.0
tournaments/season[b]	8 ± 1	8 ± 2	0.0	.912	0.1
ranking					
Velocity					
distance covered (m)	3535 ± 817	3419 ± 997	−3.3	.741	0.1
mean velocity (m/s)	0.7 ± 0.1	0.7 ± 0.1	0.0	.319	0.3
peak velocity (m/s)	4.4 ± 0.5	4.2 ± 0.5	−4.5	.269	0.5
0 to <1 m/s (s)	3289 ± 480	3375 ± 459	+2.6	.592	0.2
1 to <2 m/s (s)	1442 ± 353	1366 ± 437	−5.3	.578	0.2
2 to <3 m/s (s)	115 ± 49	112 ± 61	−2.6	.922	0.0
3 to <4 m/s (s)	22 ± 10	20 ± 13	−9.1	.567	0.2
≥4 m/s (s)	4 ± 3	2 ± 2	−50.0	.250	0.6
Acceleration					
2 to <4 m/s^2 (s)	59 ± 13	60 ± 18	+1.7	.918	0.0
≥4 m/s^2 (s)	15 ± 11	23 ± 24	+53.3	.251	0.4
Deceleration					
−2 to >−4 m/s^2 (s)	50 ± 15	45 ± 19	−10.0	.572	0.2
≤−4 m/s^2 (s)	6 ± 2	5 ± 2	−16.7	.581	0.2
Metabolic power					
energy expenditure (kJ/kg)	16.2 ± 3.8	15.5 ± 4.7	−4.3	.668	0.2
mean metabolic power (W/kg)	3.3 ± 0.3	3.1 ± 0.5	−6.1	.198	0.5
peak metabolic power (W/kg)	83.0 ± 25.9	79.5 ± 20.0	−4.2	.715	0.2
0 to <10 W/kg (s)	4708 ± 819	4716 ± 779	+0.2	.816	0.0
10 to <20 W/kg (s)	131 ± 45	126 ± 58	−3.8	.807	0.1
20 to <35 W/kg (s)	26 ± 9	24 ± 12	−7.7	.741	0.2
35 to <55 W/kg (s)	6 ± 3	5 ± 3	−16.7	.546	0.3
≥55 W/kg (s)	1 ± 1	1 ± 1	0.0	.840	0.1

[a] Difference calculated from the perspective of adult players. [b] Season is from May to July.

contrasts with a recent observation in top players, where losing players covered 10% more distance per rally than winning players.[28] One explanation for this inconsistency may be related to different playing levels. In this context, it is conventional to assume that success in tennis is multifactorially determined.[3,25] However, at a top level of play, technical-tactical skills are key factors.[27] Thus, in top players it can be expected that winning players are able to control rallies via superior technical-tactical skills (eg, topspin strokes at sharper angles across the full court dimensions), potentially leading to losing players' having to cover greater distances. However, it is not reasonable to expect this same situation in adolescent players, in whom a reduction in unforced errors is most likely related to success,[36] and this may explain why no differences in running activity between adolescent winning and losing players were found here.

The last new finding was that differences in running activity between adult winning and losing players were detected with regard

Table 3 Differences in Anthropometric Characteristics, Tennis Backgrounds, and Running Activities During Simulated Match Play Between Adult Winning and Losing Players, Mean ± SD

Variable	Adult winning players (n = 10)	Adult losing players (n = 10)	Diff (%)[a]	*P*	ES
Anthropometric characteristics					
age (y)	26 ± 4	24 ± 5	−7.7	.311	0.6
body height (cm)	185 ± 5	185 ± 9	0.0	.957	0.0
body mass (kg)	79 ± 8	80 ± 10	+1.3	.786	0.1
body-mass index (kg/m^2)	23 ± 1	23 ± 3	0.0	.699	0.2
Tennis background					
tennis experience (y)	19 ± 4	18 ± 4	−5.3	.605	0.3
training sessions/wk	3 ± 1	3 ± 1	0.0	.373	0.3
tournaments/season[b]	17 ± 7	17 ± 7	0.0	.836	0.1
ranking	3 ± 2	4 ± 2	+33.3	.686	0.2
Velocity					
distance covered (m)	3354 ± 931	3135 ± 891	−6.5	.558	0.2
mean velocity (m/s)	0.7 ± 0.1	0.6 ± 0.1	−14.3	.355	0.5
peak velocity (m/s)	5.3 ± 1.2	5.6 ± 1.6	+5.7	.634	0.2
0 to <1 m/s (s)	3521 ± 640	3707 ± 727	+5.3	.514	0.3
1 to <2 m/s (s)	1391 ± 485	1224 ± 561	−12.0	.483	0.3
2 to <3 m/s (s)	92 ± 47	79 ± 42	−14.1	.458	0.3
3 to <4 m/s (s)	20 ± 15	18 ± 9	−10.0	.613	0.2
≥4 m/s (s)	10 ± 9	7 ± 5	−30.0	.211	0.4
Acceleration					
2 to <4 m/s^2 (s)	67 ± 21	57 ± 21	−14.9	.313	0.5
≥4 m/s^2 (s)	47 ± 26	38 ± 39	−19.1	.598	0.3
Deceleration					
−2 to >−4 m/s^2 (s)	40 ± 12	36 ± 17	−10.0	.527	0.3
≤−4 m/s^2 (s)	10 ± 4	10 ± 3	0.0	.700	0.1
Metabolic power					
energy expenditure (kJ/kg)	15.4 ± 4.8	14.0 ± 4.6	−9.1	.483	0.3
mean metabolic power (W/kg)	3.0 ± 0.5	2.7 ± 0.6	−10.0	.255	0.5
peak metabolic power (W/kg)	128.6 ± 31.1	120.5 ± 35.7	−6.3	.550	0.2
0 to <10 W/kg (s)	4860 ± 831	4884 ± 820	+0.5	.919	0.0
10 to <20 W/kg (s)	124 ± 59	103 ± 54	−16.9	.383	0.4
20 to <35 W/kg (s)	37 ± 18	37 ± 12	0.0	.970	0.0
35 to <55 W/kg (s)	10 ± 5	9 ± 3	−10.0	.486	0.3
≥55 W/kg (s)	3 ± 3	2 ± 2	−33.3	.408	0.4

[a] Difference calculated from the perspective of adult players. [b] Season is from May to July.

to the number of accelerations toward the backhand and forehand corners. That is, adult winning players performed more accelerations in category 2 to <4 m/s^2 toward the forehand corner (Figure 2[E]), whereas adult losing players performed more accelerations in categories 2 to <4 and ≥4 m/s^2 toward the backhand corner (Figures 2[E] and 2[F]). While previous studies employed different standardized testing protocols to detect factors that discriminate between more- and less-successful players,[21,26] this study reveals new information concerning such factors during simulated match play. An explanation for our observations may also be the differences in technical-tactical skill levels. Again, only in top players can similar forehand and backhand stroking skills be expected. In our adult players, who can be classified based on their rankings as well-trained subelite players (Table 1), the backhand was usually weaker.[37] Thus, a common playing strategy to succeed is to attack the backhand of the opponent and to cover the playing field with one's own forehand.[37] Therefore, this tactical behavior could explain the differences we found in movement directions between adult winning and losing players.

Future studies should examine running activity in tennis players of various backgrounds (eg, different playing levels) using GPS and inertial-sensor technologies not only during simulated match play, as investigated here, but also during real competitions. This idea is timely because the rules of the International Tennis Federation were recently changed and now allow the use of approved technologies (ie, player-analysis technology) during official competitions.[6] More research is also needed to determine within-subject variations of running activity across several matches, which is important to judge the threshold above which effects are worthwhile.[35] Finally, to allow a better understanding of running activity in tennis, it is necessary to investigate its association with physical capacity (eg, power, agility, and intermittent endurance), as well as technical (eg, stroking velocity, spins, and precision) and tactical skills (eg, different playing strategies) during play.

Conclusions and Practical Applications

This study shows that differences in running activity between adolescent and adult tennis players exist in high-intensity measures during simulated match play. Furthermore, differences between adolescent and adult players, and also between adult winning and losing players, are present in terms of movement directions. It is likely that our detected differences in running activity are primarily related to differences in technical-tactical skill levels, which should be noticed by coaches in their overall training schedule. That is, in both age groups of tennis players, the focus should be placed on technical-tactical skill training.[4,27] However, to succeed, our observed differences in movement directions indicate that different training emphases should be applied. While technical-tactical skill training in adolescents may accentuate the reduction of unforced errors,[36] training in adults may highlight the realization of playing strategies (eg, to attack the usually weaker backhand of the opponent).[37] During such workouts, our presented global and high-intensity indices can serve as a framework to mimic the different match-play running demands of both age groups of players. Because technical-tactical skill training can also affect players physical capacity,[38,39] isolated physical training for increasing running capacity is potentially only needed under certain circumstances, for example, during the off-season, after injuries, or in players with obviously insufficient fitness levels. Then, additionally performed on-court interval runs[39] and off-court plyometric or resistance-training programs[5] can be beneficial to support adaptation processes.

Acknowledgments

The authors are grateful to Marie-Denise Lefter-Dumitrescu and Jutta Bornefeld for their assistance during the data assessment and to Joana Brochhagen for her linguistic comments.

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