



Sleep changes from off-season to in-season periods: effects on balance and jumping performance in young high-level tennis players

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Abstract

Purpose Sleep has been identified as an important factor influencing performance, as well as sex and chronotype. The study aimed to investigate: (I) sleep changes in tennis season periods; (II) sleep influence on balance and lower-limb strength; (III) sex and chronotype influences.

Methods Participants filled out a questionnaire to evaluate their chronotype. Sleep habits, balance, and lower limbs strength were evaluated in two season periods: off- and in-season. Forty percent of participants worsened their sleep duration from off- to in-season. Based on this, two groups were made: the worsened sleep group (WSG) and the improved sleep group (ISG).

Results The WSG showed a decrease in balance performance across all test conditions. This was evidenced by significantly higher Sway Path Length (SPL) and Sway Average Speed (SAS) values in double-leg stance (DLS) both with eyes open (EO) and eyes closed (EC) (p range from 0.043 to <0.001), as well as in single-leg stance (SLS) (p range from 0.018 to 0.010) from off-season to in-season period. Furthermore, gender-specific differences were also observed. Females had significantly worse SPL and SAS values in right SLS ($p \leq 0.043$), while males significantly increased SAS in DLS with EO ($p = 0.044$), and SPL, SAS, and Sway Ellipse Area (SEA), in DLS with EC ($p \leq 0.018$). No sleep effects were found in jumping performance. Evening types showed the lowest SEA in left SLS than the other chronotypes, and at in-season compared to off-season (all $p < 0.001$).

Conclusions Sleep remains a critical determinant of performance. Indeed, a reduction in sleep quantity was associated with a significant decline in balance performance, while no effect on jumping performance was observed. The strength of this association may be affected by athletes' transition from off-season to in-season. This study suggests that individual factors such as sex and chronotype can influence these associations. These results offer valuable insights that require further investigations.

Keywords Jumping performance · Body balance · Postural control · Sleep · Sport performance · Tennis

Abbreviations

M-types Morning-types

N-types Neither-types

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E-types	Evening-types
PSQI	Pittsburgh sleep quality index
cMEQ	Morningness-eveningness questionnaire for children
SJ	Squat jump
CoP	Center of pressure
SEA	Sway ellipse area
SPL	Sway path length
SAS	Sway average speed
DLS	Double-leg stance
SLS	Single-leg stance
EO	Eyes open
EC	Eyes closed
WSG	Worsened sleep group
ISG	Improved sleep group

Introduction

Sleep is a fundamental biological process for physiological recovery and cognitive function, and plays a crucial role in sport performance and injury risk [1, 2]. Although it has been demonstrated that athletes require more hours of sleep than other people, many of them suffer from sleep disorders such as obstructive sleep apnea, insomnia, circadian rhythm disorders, and sleep deprivation that compromise their sleep quality and quantity [3, 4]. This is even greater the higher the level of sport practiced. Indeed, Olympic athletes showed a lower sleep efficiency and a higher sleep fragmentation index compared to amateur athletes [5].

Several factors influence athletes' sleep and subsequent performance, including training schedules, travel, and psychological stressors, such as competition-related anxiety [1, 6–8]. In addition, individual characteristics such as sex and chronotype (morning, neither, or evening type) play a key role in determining sleep–wake timing and physical activation patterns [9].

The impact of these factors on sport performance often varies between different seasonal periods, such as off-season and in-season. Although not directly evaluated as the primary aim in previous studies, it seems that athletes' sleep worsens from off-season to in-season, with greater effects closer to competitions. Carter et al. (2020) showed that, during the off-season period, a small percentage of participants suffered from sleep disorders or exhibited altered sleep [10]. In particular, 35% of participants were bad sleepers, 19% suffered from excessive daytime sleepiness, and 28% had insomnia symptoms. By contrast, several studies have reported a high prevalence of sleep disturbances and insufficient sleep duration among athletes during the in-season period (often attributed to increased competitive stress and demanding travel schedules) which may lead to significant

sleep fragmentation and further exacerbation of physiological stress [1, 11–14].

A recent review analyzing the effects of sleep quality in athletes of different sports showed that several physical characteristics, such as strength and endurance, can be negatively influenced by sleep deprivation [15]. As concerning tennis, after a sleep deprivation of 5 h total sleep/night, serve accuracy and forehand and backhand crosscourt shots decreased in semi-professional tennis players [8, 16]. By contrast, a sleep extension of 2 h more sleep/night over 1 week improved serve accuracy in collegiate varsity tennis players [17]. As for young tennis players, a high-level junior tennis tournament usually has intensive schedules and sometimes up to three matches per day. These demanding routines impose not only substantial physical effort but also high cognitive load [18, 19] which can degrade sleep quantity and quality [20], and consequently affect tennis players' performance [21].

Studies have shown that balance is related to athletic performance [22, 23]. This is even more emphasized in young tennis players [24, 25], as this sport is characterized by complex multi-directional and explosive movements that require high balance. These findings suggest that balance plays a key role in tennis practice. Since sleep deprivation and disorders affect balance [6], this could compromise athletes' performance. Research highlights that activities requiring precision and high levels of movement control, such as balance, are particularly sensitive to sleep deprivation [26]. This sensitivity arises, because sleep deprivation negatively impacts the three core pillars of postural regulation: information acquisition (e.g., visual and vestibular inputs), decision-making (i.e., central integration and executive function), and motor execution (i.e., muscle coordination). As described by Paillard (2023), these are critical for athletes, because specialized motor skills rely heavily on the efficient mobilization of these neurobiological resources [26]. When these systems are compromised, there is an inability to successfully update the perception of action capabilities, resulting in less stable and less precise motor executions.

Similarly, among predominant sport-specific technical skills in tennis, strength has a crucial role [27, 28]. As a matter of fact, high strength is required for these skills [29]. Indeed, it has been noted a relationship between the levels of upper and lower-limb muscular strength and ranking position in competitive tennis players [30, 31]. In tennis, as for other sports, jumping performance is of fundamental importance in order to reach the ball in motion as well as for serving, and these are strictly related to lower and upper-limb strength, respectively [32, 33]. In particular, vertical jump performance is an informative performance indicator for tennis-specific change of direction [34]. Specifically, as the vertical jump height (measured with a squat jump or

countermovement jump test) increases, the time taken to complete a change of direction test decreases [34].

Therefore, considering that (1) balance and lower-limb strength are related to sport performance in tennis and they can be affected by athletes' sleep, and that (2) athletes' sleep is generally altered in relation to the sport-season periods, it is necessary to explore these factors in youth athletes. To the best of our knowledge, no studies have focused on this aspect in young high-level tennis players. The aim of this study was to investigate sleep changes in young high-level tennis players in two different season periods (i.e., off- and in-season) and to evaluate sleep influence on balance and lower-limb strength. Moreover, the study aimed to investigate the influences of sex and chronotype on sleep, balance, and lower-limb strength.

Methods

Study design and procedure

The present study consisted of two phases. During the first one, participants were recruited after checking inclusion and exclusion criteria and the administration of written informed consent. Subsequently, in the same phase (i.e., off-season period—last week of October), participants filled out a questionnaire to evaluate their chronotype and sleep habits, and they performed balance and jumping performance tests. In the second phase (i.e., in-season period—last week of May), participants filled out the questionnaire to evaluate again their sleep habits, and they performed balance and jumping performance tests.

Test administration, carried out by the same investigators, took place in the same silent room of a Sicilian tennis club during the same time slot in order to minimize time-of-day effect.

Participants

Participants were recruited from a Sicilian tennis club, and to be included in the study, participants must meet the following inclusion criteria: to be registered in the Italian Tennis Federation (Federazione Italiana Tennis—FIT) as an athlete; to participate regularly in regional and/or national level tournaments; to have at least 3 years of tennis experience. Participants could not be included if they had: any type of musculoskeletal injury during 6 months prior to the test sessions or visual and/or hearing impairment.

Based on the inclusion and exclusion criteria, 29 participants were enrolled in the study. However, only 15 participants (7 males and 8 females; 12.20 ± 0.58 years; 44.07 ± 2.63 kg; 157.00 ± 3.69 cm) completed both testing sessions. This is because, from off-season period to

in-season period, some participants moved to other tennis clubs and others did not make themselves available for the second evaluation.

As the participants were minors, parents provided written informed consent for their participation. The study complied with the recommendations of the Declaration of Helsinki and was approved by the Bioethics Committee of the University of Palermo (n. 131/2023—prot. 28387-23/02/2023).

Circadian typology

The Morningness–Eveningness Questionnaire for children (cMEQ) is a questionnaire with an adaptation and reduction of the original version of the Morningness–Eveningness Questionnaire [35], investigating the circadian typology in children and adolescents. The questionnaire, administered in the Italian version, consists of 10 closed-answer items, specifically reformulated on the basis of the school and social reality experienced by children and adolescents [36]. The questions investigate the habits of waking up and going to bed, the moments of the day in which the subject feels more active and performs better, as well as the moments of the day in which the subject is tired and needs to sleep. Each answer has a score (from 0 to 5) and the total sum defines the subject's chronotype. The maximum score is 42 (morning-oriented people) and the minimum score is 10 (evening-oriented people).

Sleep quantity

Participants' sleep quantity was assessed using a questionnaire focusing on self-reported bedtime, wake-up time, and time required to fall asleep. Sleep duration was calculated by subtracting the time to fall asleep from the total time spent in bed. To ensure a direct temporal relationship with the performance tests, participants provided these estimates based on their habits during the week immediately preceding each testing session.

Squat jump test

The squat jump (SJ) test was administered using the Opto-jump photoelectric cell system (Microgate, Bolzano, Italy) consisting of two bars (one receiver and one transmitter unit) placed on the floor parallel to and 1 m apart from each other [37]. The transmitting bar is made up of light-emitting diodes which by communicating with the receiving bar are capable of measuring the flight time of vertical jumps with an accuracy of 1/1000 s (1 kHz). The related software calculates the vertical jump height as $9.81 \times \text{flight time}^2/8$ [38].

Participants were asked to start from the upright position with hands on the hips, and then to flex the knees and keep them at about a 90° angle position. At the beep the

participants were asked to jump as high as possible without performing any countermovement before the execution of the jump. Participants were asked to keep their knees and ankles extended during both take-off and landing. Each participant performed three trials with a rest of 3 min between them. The best performance recorded was considered for statistical analysis.

Stabilometric test

The stabilometric test was carried out using a posturographic system consisting of the freeMed Maxi platform and the freeStep software (Sensor Medica, Guidonia Montecelio, Rome, Italy). The platform is made up of resistive, gold-coated 24 k sensors capable of detecting a pressure of up to 150 N/cm² and acquiring at a frequency of up to 400 Hz. For all the measurements, the signal was digitized with a sampling frequency of 50 Hz. The posturographic system measures the Center of Pressure (CoP) displacement and transforms the acquired data into CoP coordinates. The following parameters, which are the main parameters regarding the CoP displacement, were considered: Sway Ellipse Area (SEA), Sway Path Length (SPL), Sway Average Speed (SAS).

Participants performed the stabilometric tests in double-leg stance (DLS) and in single-leg stance (SLS). As for the stabilometric tests in DLS, participants were asked to stand barefoot in an upright position on the stabilometric platform for 51.2 s with the head in a neutral position, arms along the trunk, and feet forming a 30° angle with heels 2 cm apart. The test was conducted first with eyes open (EO) and then repeated with eyes closed (EC). In the EO condition, participants were asked to gaze at an eye-level point at a 1 m distance. As concern the stabilometric tests in SLS, participants were asked to stand barefoot in one-leg on the stabilometric platform for 10 s with the other knee flexed at about a 90° angle position, head in a neutral position, and hands on the hips. The test was conducted with both the right and left legs with eyes open (EO), in which participants were asked to gaze at an eye-level point at a 1 m distance.

Statistical analysis

Means and standard errors were calculated for quantitative variables and frequencies for qualitative variables.

Shapiro–Wilk’s and Levene’s tests were used to evaluate the normal distribution and homogeneity of the data, respectively.

In order to analyze the impact of different sleep conditions on performance, the sample was divided into two groups based on the worsened or improved sleep duration between PRE and POST (i.e., off- and in-season): the

worsened sleep group (WSG) and the improved sleep group (ISG).

Paired *t* tests were used to investigate PRE–POST differences in sleep and performance between WSG and ISG and between males and females. Unpaired *t* tests were used to compare WSG and ISG, as well as males and females at PRE and at POST.

Analysis of variance (ANOVA) for repeated measures was performed to investigate sleep and performance differences between the three chronotypes in the two periods, evaluating within and between effects. Bonferroni’s adjustments were used in post hoc comparisons.

We investigated the strength of significant comparisons by evaluating the effect size according to Cohen’s *d* interpretation (small: $0.2 \leq d < 0.5$; medium: $0.5 \leq d < 0.8$; large: $d \geq 0.8$) [39].

A post hoc power analysis was conducted to detect the achieved sample size power, using G*Power software (v. 3.1.9.2; Heinrich Heine University, Düsseldorf, Germany) [40].

Statistical analyses were performed using SPSS Statistics version 27 (IBM SPSS Statistics for Windows, Armonk, NY, USA: IBM Corp). The statistical significance was set at $p < 0.05$.

Results

Based on the sample size enrolled (i.e., $n = 15$ participants who completed both testing sessions), the retrospective statistical power was 32%.

The highest percentage of participants were N-types (47%, $n = 7$), followed by M-types (33%, $n = 5$), and E-types (20%, $n = 3$).

The sample showed that only 3 participants out of 15 (20%) reached the recommended 9–11 h of sleep proposed by the National Sleep Foundation [41] at PRE. From off- to in-season, 6 participants (40%, 4 females and 2 males) worsened their sleep duration (Δ sleep duration: $-01:07:30 \pm 00:24:59$), while 8 participants (53%, 3 females and 5 males) improved it (Δ sleep duration: $01:24:22 \pm 00:25:58$). Despite this sleep improvement, only 3 participants (20%) reached the recommended sleep quantity threshold at POST. Only one female participant (7%, E-type) did not change her sleep duration between the two periods, and she was excluded from the subsequent analyses.

In order to analyze the impact of different sleep conditions on performance, the total sample was divided into two groups based on the reduction or increase in sleep duration: the worsened sleep group (WSG) and the improved sleep group (ISG).

The WSG showed a statistically significant decrease in sleep duration ($08:59:10 \pm 00:33:15$ vs $07:51:40 \pm 00:30:55$,

$p=0.043$, $d>0.08$, PRE vs POST, respectively). By contrast, the ISG showed a statistically significant increase in sleep duration ($06:54:23 \pm 00:21:23$ vs $08:18:45 \pm 00:21:23$; $p=0.014$, $d>0.08$, PRE vs POST, respectively). Paired t test comparisons showed, only for the WSG, a statistically significant increase in SPL ($p=0.043$, $d>0.8$) and SAS ($p=0.034$, $d>0.8$) in DLS with EO, in SPL ($p<0.001$, $d>0.8$) and SAS ($p<0.001$, $d>0.8$) in DLS with EC, and in SPL ($p=0.006$, $d>0.8$) and SAS ($p=0.006$, $d>0.8$) in right SLS. No differences were found in the ISG (Table 1). Unpaired t test comparisons at POST showed a statistically significant higher SPL ($p=0.018$, $d>0.8$) and SAS ($p=0.018$, $d>0.8$) in left SLS, and in SPL ($p=0.010$, $d>0.8$) and SAS ($p=0.010$, $d>0.8$) in right SLS between the two groups. No other differences were found at POST and at PRE between the two groups (Table 1). In summary, the WSG exhibited a significant decrease in balance performance across all test conditions, showing lower performance not only from PRE to POST but also at POST when compared to the ISG.

In the sex PRE–POST comparisons, females showed a statistically significant worsening in SPL ($p=0.043$, $d>0.8$) and in SAS ($p=0.041$, $d>0.8$) in the right SLS. By contrast, males showed a statistically significant increase in SAS ($p=0.044$, $d>0.8$) in DLS with EO, and in SEA ($p=0.018$, $d>0.8$), SPL ($p=0.013$, $d>0.8$), and SAS ($p=0.013$, $d>0.8$) in DLS with EC (Table 2). Moreover, females showed lower SJ performance than males, both at PRE ($p=0.007$, $d>0.8$) and POST ($p=0.018$, $d>0.8$) (Table 2). These findings highlight that while jumping performance remained higher in males in both season periods, the decline in balance performance followed a sex-specific

pattern: females exhibited a significant reduction mainly in SLS, while males showed a greater decrease in DLS, especially with EC.

Chronotype analyses showed a statistically significant difference only in SEA ($F=8.622$, $df=2$, $p=0.006$, $\eta^2=0.611$) in left SLS (Table 3). In particular, from PRE to POST, E-types showed the lowest levels than the other two chronotypes ($p<0.001$, $d>0.8$). E-types also showed the worst performance in the same test carried out in the POST ($p<0.001$, $d>0.8$ and $p<0.001$, $d>0.8$, E-types vs M-types and N-types, respectively) (Table 3). Although not statistically significant, a lower performance was found at POST in SPL ($p=0.067$) in left SLS and in SAS ($p=0.069$) in left SLS, with E-types that showed the worst performance. In summary, balance performance differed significantly according to the athlete's chronotype, with E-types showing poorer balance compared to both M-types and N-types.

Discussion

The present study aimed to evaluate sleep quantity in young high-level tennis players from the off- to the in-season period, also investigating the relationship between sleep and balance, as well as between sleep and lower-limb strength. Moreover, it aimed to investigate the influences of sex and chronotype on sleep, balance, and lower-limb strength.

The main findings of the present study show that a higher percentage of young tennis players (80%) displayed an insufficient sleep quantity in both off- and in-season periods. Moreover, from off-season to in-season, 40% of participants worsened their sleep duration. By contrast, 53% of

Table 1 PRE–POST comparisons of balance and jumping performance in WSG and ISG

TESTS		WSG		ISG	
		PRE	POST	PRE	POST
SJ		17.88 $\pm$ 2.06	19.02 $\pm$ 1.89	22.79 $\pm$ 2.74	23.93 $\pm$ 2.66
DLS EO	SEA	397.51 $\pm$ 171.73	618.53 $\pm$ 178.71	167.03 $\pm$ 52.30	284.78 $\pm$ 60.78
	SPL	829.20 $\pm$ 106.40*	1206.81 $\pm$ 85.16*	698.54 $\pm$ 91.34	1020.31 $\pm$ 138.74
	SAS	16.49 $\pm$ 2.14 [#]	24.89 $\pm$ 1.78 [#]	14.26 $\pm$ 1.92	21.43 $\pm$ 3.11
DLS EC	SEA	230.19 $\pm$ 45.41	969.04 $\pm$ 471.90	195.81 $\pm$ 59.44	259.26 $\pm$ 62.44
	SPL	805.01 $\pm$ 103.81 [°]	1193.49 $\pm$ 61.80 [°]	784.14 $\pm$ 126.63	1021.18 $\pm$ 133.10
	SAS	15.99 $\pm$ 2.06 ⁺	24.51 $\pm$ 1.10 ⁺	15.86 $\pm$ 2.58	21.54 $\pm$ 3.01
Left SLS	SEA	586.63 $\pm$ 121.70	1216.81 $\pm$ 418.26	323.19 $\pm$ 70.42	574.05 $\pm$ 65.10
	SPL	336.46 $\pm$ 37.39	445.47 $\pm$ 53.28 [^]	256.02 $\pm$ 34.46	301.54 $\pm$ 22.31 [^]
	SAS	33.66 $\pm$ 3.78	44.73 $\pm$ 5.32 [@]	25.86 $\pm$ 3.55	30.41 $\pm$ 2.25 [@]
Right SLS	SEA	628.56 $\pm$ 348.05	1072.60 $\pm$ 518.53	830.52 $\pm$ 150.41	731.27 $\pm$ 168.19
	SPL	285.58 $\pm$ 40.43 [°]	457.85 $\pm$ 44.00 [°] [†]	288.06 $\pm$ 40.68	311.32 $\pm$ 25.36 [†]
	SAS	28.66 $\pm$ 4.08 [§]	45.88 $\pm$ 4.37 [§] [°]	28.95 $\pm$ 4.08	31.40 $\pm$ 2.54 [°]

* $p=0.043$; [#] $p=0.034$; [°] $p<0.001$; ⁺ $p<0.001$; [°] $p=0.006$; [§] $p=0.006$; [^] $p=0.018$; [@] $p=0.018$; [†] $p=0.010$; [°] $p=0.010$. mean $\pm$ se. DLS double-leg stance, EC eyes closed, EO eyes open, SAS sway average speed, SEA sway ellipse area, SJ squat jump, SLS single-leg stance, SPL sway path length

Table 2 PRE–POST comparisons of balance and jumping performance in females and males

TESTS		PRE		POST	
		Females	Males	Females	Males
Sleep duration		08:29:17 ± 00:39:32	07:06:26 ± 00:20:03	08:40:00 ± 00:19:24	07:34:17 ± 00:24:49
SJ		16.10 ± 1.87*	25.27 ± 2.11*	17.81 ± 2.13 [#]	25.83 ± 2.01 [#]
DLS EO	SEA	373.79 ± 155.90	157.82 ± 29.30	533.53 ± 172.43	322.09 ± 58.08
	SPL	770.71 ± 89.97	738.37 ± 111.46	1050.76 ± 116.02	1149.71 ± 139.32
	SAS	15.62 ± 1.91	14.81 ± 2.21 [°]	21.57 ± 2.37	24.26 ± 3.14 [°]
DLS EC	SEA	221.26 ± 64.14	199.83 ± 46.13 [°]	738.82 ± 438.23	388.09 ± 55.63 [°]
	SPL	867.06 ± 151.16	719.12 ± 66.66 [§]	1055.68 ± 110.41	1134.38 ± 126.76 [§]
	SAS	17.47 ± 3.05	14.36 ± 1.34 ⁺	21.64 ± 2.22	23.98 ± 2.88 ⁺
Left SLS	SEA	504.67 ± 113.50	367.52 ± 91.70	823.52 ± 223.68	875.52 ± 337.75
	SPL	300.09 ± 36.09	280.90 ± 42.15	369.07 ± 50.63	357.38 ± 42.51
	SAS	30.23 ± 3.71	28.18 ± 4.23	37.15 ± 5.12	35.94 ± 4.16
Right SLS	SEA	645.73 ± 129.62	842.19 ± 167.03	931.81 ± 243.90	823.31 ± 137.00
	SPL	251.58 ± 27.59 [@]	322.41 ± 46.85	373.95 ± 56.13 [@]	374.29 ± 29.02
	SAS	25.25 ± 2.79 [^]	32.39 ± 4.70	37.48 ± 5.55 [^]	37.73 ± 2.92

*p=0.007; [#]p=0.018; [°]p=0.044; [°]p=0.018; [§]p=0.013; ⁺p=0.013; [@]p=0.043; [^]p=0.041. Mean ± se. *DLS* double-leg stance, *EC* eyes closed, *EO* eyes open, *SAS* sway average speed, *SEA* sway ellipse area, *SJ* squat jump, *SLS* single-leg stance, *SPL* sway path length

Table 3 PRE–POST comparisons of balance and jumping performance among the three chronotypes

TESTS		PRE			POST		
		M-types	N-types	E-types	M-types	N-types	E-types
Sleep duration		07:57:00 ± 00:34:36	07:15:43 ± 00:27:17	09:17:30 ± 01:57:30	08:13:00 ± 00:23:29	08:16:26 ± 00:22:07	07:20:00 ± 01:40:00
SJ		21.22 ± 3.57	20.73 ± 2.62	19.20 ± 6.40	24.76 ± 2.81	20.97 ± 2.74	17.45 ± 3.55
DLS EO	SEA	165.62 ± 101.23	212.35 ± 52.05	703.38 ± 473.38	391.73 ± 103.25	342.12 ± 90.83	817.95 ± 558.95
	SPL	722.22 ± 162.94	795.45 ± 85.16	692.14 ± 50.43	1106.69 ± 164.89	1043.44 ± 136.06	1282.89 ± 44.77
	SAS	14.36 ± 3.25	16.23 ± 1.77	13.81 ± 1.11	22.93 ± 3.40	21.76 ± 3.08	26.94 ± 1.61
DLS EC	SEA	223.15 ± 65.02	216.44 ± 63.54	158.39 ± 39.70	485.59 ± 159.43	688.02 ± 430.64	322.14 ± 192.05
	SPL	784.30 ± 146.70	852.90 ± 128.39	605.69 ± 47.33	1120.19 ± 161.68	1081.01 ± 127.31	1081.18 ± 3.92
	SAS	15.55 ± 2.92	17.28 ± 2.60	12.07 ± 0.83	23.30 ± 3.39	22.51 ± 2.85	22.65 ± 0.45
Left SLS	SEA	424.12 ± 114.26	381.80 ± 81.68	656.06 ± 387.64 [*]	505.08 ± 93.37 [#]	647.58 ± 116.37 [°]	2417.41 ± 426.39 ^{*#}
	SPL	277.16 ± 57.44	301.74 ± 100.83	284.47 ± 29.73	309.44 ± 39.15	347.12 ± 38.13	554.02 ± 40.35
	SAS	27.72 ± 5.76	30.51 ± 3.90	28.34 ± 2.86	31.10 ± 4.02	34.99 ± 3.77	55.58 ± 3.54
Right SLS	SEA	638.88 ± 182.38	825.24 ± 167.21	722.21 ± 187.76	944.83 ± 264.90	725.49 ± 154.74	1241.59 ± 484.37
	SPL	274.90 ± 46.45	288.59 ± 41.17	311.67 ± 112.77	369.81 ± 57.37	329.23 ± 35.54	533.09 ± 15.87
	SAS	27.61 ± 4.72	28.99 ± 2.80	31.26 ± 11.38	37.28 ± 5.75	33.36 ± 2.96	53.30 ± 1.14

*p<0.001, [#]p<0.001, [°]p<0.001. Mean ± se. *DLS* double-leg stance, *EC* eyes closed, *EO* eyes open, *SAS* sway average speed, *SEA* sway ellipse area, *SJ* squat jump, *SLS* single-leg stance, *SPL* sway path length

participants improved it, although the highest percentage of them (75%) did not reach the recommended hours of sleep. These results agree with previous studies that showed that athletes, who require more sleep hours than non-athletes, often do not reach the sleep quantity threshold recommended by the National Sleep Foundation [3, 4]. Specifically, for the mean age of the sample (12.20 ± 0.58 years), the National Sleep Foundation recommends 9–11 h of sleep per night for school-age children (6–13 years). Our findings highlight a significant gap in achieving these recommendations, as

the majority of participants failed to achieve the minimum threshold of 9 h in both season periods. Furthermore, from the off- to the in-season period, athletes are exposed to different psychophysiological stressors, such as training programs, anxiety, and stress related to the approach of the competition, and travel for competition, that could affect their sleep and mood condition [1, 7, 8].

Considering young athletes, these are enhanced by school commitments [42]. This can compromise the athletes' performance [6], regardless of sport practiced,

including tennis [8]. In agreement with these, our results demonstrated that only WSG showed a worsened balance performance. Based on this evidence, coaches should combine training programs with a process of learning strategies for managing emotions and improving the sleep quality and quantity of their athletes. In this way, athletes would have sturdy knowledge to deal with psychophysiological stressors related to high-level sport practice.

Sex and chronotype could be other factors that may influence the relationship shown above. Regarding the sex PRE–POST comparisons, our results indicated a worsened single-leg stance balance performance in females, while males showed an increase in sway average speed in double-leg stance with both eyes open and eyes closed, and a higher sway ellipse area and sway path length only in the double-leg stance with eyes closed. While males showed the lowest sleep duration both at PRE and at POST, these values did not reach statistical significance. In light of these trends, and the relationship shown between sleep and balance performance in the sample, we can hypothesize that changes in balance performance observed in males might be linked to the different sleep conditions between the sexes. Given that balance in young tennis players is related to athletic performance [24, 25], sleep could potentially affect performance indirectly by influencing balance. However, these sex-specific observations require further exploration in larger samples.

Chronotype, like sex, could be another factor that should be considered in the relationship between sleep and performance in tennis. Our results showed a statistically significant difference in the single-leg stance balance performance with the left leg. In particular, E-types showed worsened performance compared to the PRE and POST season periods, and lower performance when compared with other chronotypes at POST. Considering that our results showed no differences in sleep conditions among chronotypes, we can assume that the difference in performance is mainly determined by the time of execution of the test. Although the relationship between chronotypes and sport performance is well-documented in the literature [43, 44], the timing of our assessments likely placed E-types at a disadvantage. This highlights the importance of taking chronotype into account when assessing performance, as the alignment between an athlete's circadian typology and the timing of testing can influence physical performance. As reported in the literature, E-types usually perform better in the evening than in the morning [45], a factor which likely accentuated the observed differences between the off- and in-season periods.

This evidence demonstrated that sleep is not the only parameter that characterizes the concept of chronotype; therefore, considering the chronotype as an additional factor in the relationship between sleep, balance, and sport performance could be relevant.

The main strength of the present study was to investigate changes in sleep quantity, balance, and jumping performance between off- and in-season periods in young high-level tennis players, as well as considering sex and chronotype. Notably, all performance measurements were objective. A limitation of the study is the small sample size, which did not allow to investigate the possible combined influence of sleep, chronotype, and sex. Furthermore, although sleep duration is a key parameter, the lack of data on sleep efficiency or fragmentation limits the interpretation of the relationship between seasonal changes in sleep and athletic performance. Therefore, our findings should be interpreted specifically as the impact of self-reported changes in sleep quantity on performance, rather than a comprehensive assessment of sleep architecture or stability. The use of self-reported questionnaires could present a recall bias, which was mitigated by asking participants to report their sleep habits for the week prior to testing to ensure the data were as accurate as possible. Finally, the present study did not collect data regarding participants' biological maturation. Given that the sample consisted of youth, individual differences in biological maturation could represent a confounding factor in the assessment of balance and strength performance. Nevertheless, these results provide a valuable starting point for considering interconnected factors, such as sex and chronotype, which together may influence sport performance.

Conclusions

Seasonal periods appear to affect sport performance, likely due to variable psychophysiological stressors, such as training loads, anxiety, and competition-related travel. Sleep remains a critical determinant of sport performance. However, the strength of this association may vary in athletes from the off-season to in-season period. This study showed that the majority of the recruited high-level young tennis players did not achieve the 9 h of sleep recommended by the National Sleep Foundation, both during the off-season and in-season period. Moreover, nearly half of the participants showed a decrease in sleep quantity as the competitive season approached. The findings suggest that chronotype and sex are additional factors influencing these relationships, highlighting the inter-individuality of athletes. Considering these factors could be important for assessing athletic performance and tailoring training and recovery strategies, and planning for competition. However, while these results offer valuable insights, further large-scale studies are needed. Future research should aim to confirm the effectiveness of scheduling sleep and training sessions based on individual chronotype and sex for maximizing performance and recovery.

Author contributions AMu and VG conceptualized and designed the study, performed the formal data analysis, and wrote the manuscript; DSSV, FF, BA, FM, and JB performed the evaluations of the participants; AP revised the manuscript and interpreted the findings; IR, AC, FE, AM, and ER approved the manuscript; GM and AB conceptualized the study. All authors have read and approved the final manuscript, and agree with the order of the presentation of the authors.

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Data availability The data supporting the conclusion of this article will be made available by the authors, without undue reservation.

Declarations

Conflict of interest The authors declare no competing interests.

Informed consent and Ethical approval As the participants were minors, parents provided written informed consent for their participation. The study complied with the recommendations of the Declaration of Helsinki and was approved by the Bioethics Committee of the University of Palermo (n. 131/2023–prot. 28387-23/02/2023).

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