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Associations between objective measures of performance-related characteristics and perceived stress in young cross-country skiers during pre-season training

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ABSTRACT
Monitoring performance-related characteristics of athletes can reveal changes that facilitate training adaptations. Here, we examine the relationships between submaximal running, maximal jump performance (CMJ), concentrations of blood lactate, sleep duration (SD) and latency (SL), and perceived stress (PSS) in junior cross-country skiers during pre-season training. These parameters were monitored in 15 male and 14 females (17 ± 1 years) for the 12-weeks prior to the competition season, and the data was analysed using linear and mixed-effect models. An increase in SD exerted a decrease in both PSS (B = -2.79, $p \leq 0.01$) and blood lactate concentrations during submaximal running (B = -0.623, $p \leq 0.05$). In addition, there was a negative relationship between SL and CMJ (B = -0.09, $p = 0.08$). Compared to males, females exhibited higher PSS scores and little or no change in performance-related tests. A significant interaction between time and sex was present in CMJ with males displaying an effect of time on CMJ performance. For all athletes, lower PSS appeared to be associated with longer overnight sleep. Since the females experienced higher levels of stress, monitoring of their PSS might be beneficial. These findings have implications for the preparation of young athletes' competition season.

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KEYWORDS
Heart rate variability; adolescents; sleep duration; sleep latency

1. Introduction

During the past several decades there has been an exponential rise in the professionalism of sport and with that a greater interest in using a scientific approach has emerged (Hamlin et al., 2019). As a result, many sport practitioners apply evidence-informed methods to help maximize athlete performance. To optimize training, both the training process itself and recovery must be monitored, and a favourable balance achieved. To achieve the correct balance, there is not one definitive approach; instead, relevant and easily comprehensible feedback can improve our general understanding of training and/or recovery status, thereby aiding in the development of an appropriate training programme that also reduces the risk of injury, illness and overtraining (Halson, 2014; Murray, 2017). This feedback is obtained by monitoring objective (physiological, biochemical) and subjective (perceived physical and psychological well-being/mood) factors related to performance, recovery and/or well-being (Lamberts et al., 2011; Saw et al., 2016). Although subjective measures have demonstrated a higher sensitivity and a higher consistency when compared to objective measures, current practice typically utilizes a mixed-method approach including concurrent measures of both objective and subjective factors (Saw et al., 2016).

As a result, objective measures of physical performance, such as maximal jump and submaximal tests, are commonly employed by coaches and athletes to help monitor athletes' fatigue (Taylor et al., 2012). In addition, nocturnal heart rate (HR) and heart rate variability (HRV) are a convenient and reliable measure for monitoring training status and recovery in endurance athletes (Nuuttila et al., 2022). Furthermore, growing evidence has emerged addressing the positive relationship between sleep and optimal performance with improvements in sleep quality and quantity appearing to be an additional factor that may aid in maximizing athletic success (Simpson et al., 2017). However, it is important to recognize that athletes encounter additional challenges from social, lifestyle, academic and athlete-coach relationships and this non-training stress needs to be accounted (Hamlin et al., 2019; Solomon et al., 2017). Therefore, subjective levels of stress are an additional area that may be beneficial to follow.

One specific population of athletes that may significantly benefit from athlete monitoring are young endurance athletes. Growth and development have an evident influence on performance and young athletes aiming for success train regularly with long hours and an intense dedication (Solomon et al., 2017). Endurance research typically involves adult subjects and therefore, knowledge regarding the physiological trainability and perception of stress during the adolescent years is limited (Baquet et al., 2003; Mikkola et al., 2007; Murray, 2017; Naughton et al., 2000). In addition to the physical changes, young athletes have the additional task of balancing their studies and training. Certain times of the year, such as pre-

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season or examination periods, may elicit an increase in external pressure which can add to the overall perceived stress (Hamlin et al., 2019). Previous research has shown that changes in individual perceptions of stress/recovery are positively associated with meaningful changes in performance (Otter et al., 2015). Furthermore, earlier findings indicate the females report higher levels in certain areas of perceived stress during preseason periods (Roberts et al., 2022) and consistently higher amounts of overall stress when compared to males (Brougham et al., 2009). These findings suggest that communication about feelings and levels of stress may be as relevant as performance-related tests, and further investigation in this area, and independent of sex, may be of importance for coaches and athletes. Consequently, longitudinal studies following subjective and objective measures of young athletes are needed (Baquet et al., 2003).

Therefore, our primary aim here was to investigate the relationship between various objective measures of training and recovery and subjective stress. Our secondary objective was to examine changes in submaximal running, jump performance, the duration and latency of sleep, nocturnal HR and perceived stress in young athletes during the 4-month period of pre-season training and determine which of these factors exert a significant impact on their performance. In addition, we have explored potential sex differences in these contexts.

2. Methods

2.1. Participants and design

The 29 well-trained young endurance athletes who participated in the research were students at a sports high school, who trained and competed in cross-country skiing or biathlon all year round. The athletes had at least 3 years of competition experience at the national level, and their baseline characteristics and training background are shown in Table 1. All subjects were fully informed of the experimental procedures and provided written consent before taking part in this study. An ethical committee from the Central Finland Health Care District approved the study (Ethical reference number: Dnro 14 U/2018) and measurements were performed in accordance with the Declaration of Helsinki (World Medical Association, 2013).

The research took place during a 4-month pre-season period of endurance training and racing for cross-country skiing or biathlon. This study period began in August and ended in November right before the winter competition season began (Figure 1). Nocturnal HR, HRV, duration of sleep and sleep latency were monitored daily throughout the study period. Additional measures were obtained in the morning once a month in a laboratory setting. Total measurement time was approximately 30 minutes. Each measurement started with a measure of general stress level of the subjects by completing a monthly perceived stress questionnaire (Cohen et al., 1983). Once the survey was complete, maximal countermovement jump tests were conducted followed by submaximal running tests to follow performance-related parameters. During these tests, HR, blood lactate concentrations and rate of perceived exertion (RPE) were collected. RPE was reported before the test began and during the last 30 seconds of each running stage and assessed using a category ratio RPE scale (Baquet et al., 2003; Borg, 1970, 1970; Brougham et al., 2009; Cohen et al., 1983; Hynynen et al., 2006; Mikkola et al., 2007; Naughton et al., 2000; Nuuttila et al., 2022; Otter et al., 2015; Roberts et al., 2022; Simpson et al., 2017; Solomon et al., 2017; Taylor et al., 2012; Walvekar, 2015; World Medical Association, 2013). Running and jump exercises were already incorporated into the tested individuals' normal training; thus, a preparatory training period was unnecessary. Due to the longitudinal design of this study, measurement weeks were carefully considered with coaches to avoid weeks that included training camps or exams.

2.2. Perceived stress survey

The 14-item Cohen Perceived Stress Scale (PSS) was used to assess monthly levels of perceived stress. The PSS is a reliable and validated psychological tool that was developed to

Table 1. Characteristics of the participants (means ± SD).

	Males ($N = 15$)	Females ($N = 14$)
Age (yrs.)	17 ± 1	17 ± 1
Height (cm)	179.2 ± 6.6	167.6 ± 6.2
Body mass (kg)	70.7 ± 8.9	62.6 ± 5.0
VO_2max (mL/kg/min)	66.1 ± 4.4	54.2 ± 2.1
Maximal heart rate (bpm)	199 ± 9	200 ± 6
Annual training (hrs.)	544 ± 65	557 ± 54

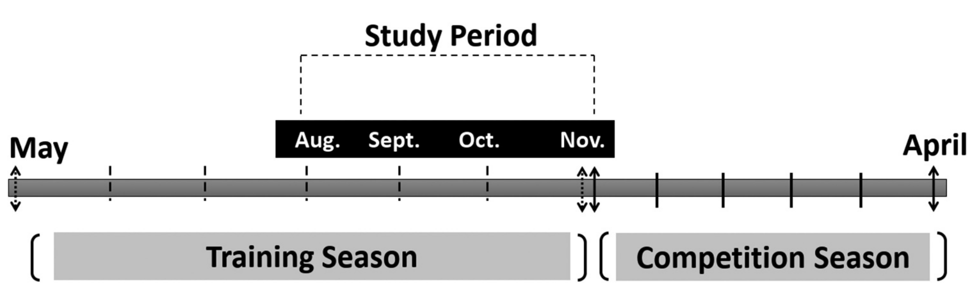

Figure 1. Timeline of the investigated study period.

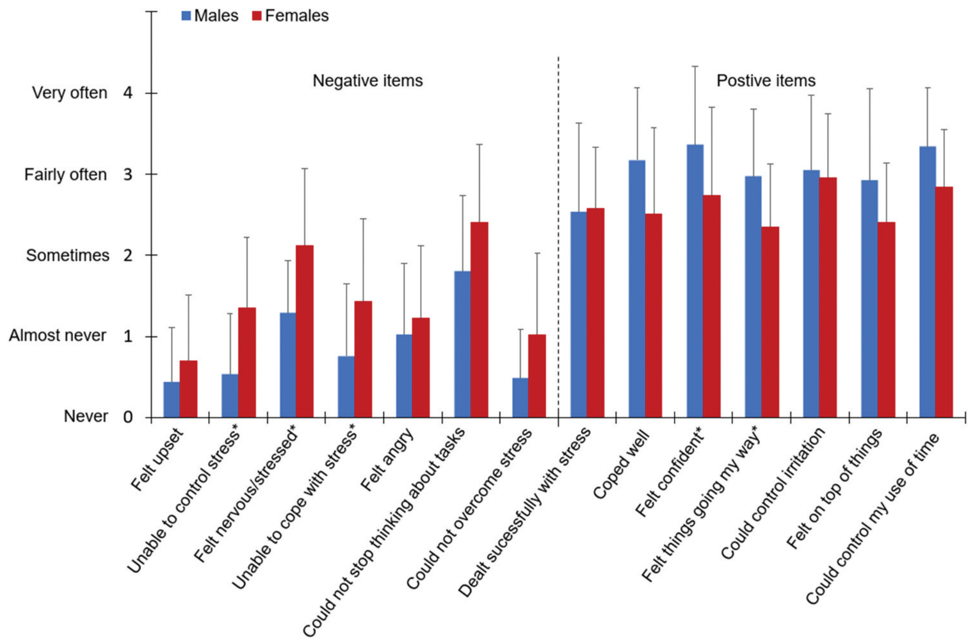

Figure 2. Scores on the different items of the perceived stress test during the pre-season training period.
*Significant difference between males and females, $p \leq 0.05$

measure stress from the psychological perspective (Cohen et al., 1983; Hynynen et al., 2006). It consists of seven negative and seven positive items with the negative element intended to assess the lack of control and the positive element focused on the individual's ability to cope with existing stressors (Walvekar, 2015). (Figure 2) A five-point Likert-type scale, ranging from 0, "Never" to 4, "Very Often" was used to rate each item. Possible scores ranged from 0 to 56 with higher scores indicating higher levels of perceived stress. The scores may be further categorized into three levels: scores 0–13 indicate low stress, scores 14–26 indicate moderate stress and scores 27–40 indicate high stress (Hrozanova et al., 2019). Subjects were instructed to sit down and fill out the stress survey upon their arrival to the testing laboratory. Surveys were conducted prior to performance tests to ensure that subjects were well rested and able to properly answer all questions without any external influence due to performance test results.

2.3. Maximal jumps and submaximal running test

Maximal counter movement jumps (CMJ) (Bosco et al., 1983) and submaximal running tests (SRT) were used to evaluate athletes' performance-related characteristics and/or recovery. Prior to arrival, subjects completed a 15-minute warm-up running at a self-selected sub-maximal speed. Subjects were then instructed to jump as high as possible while keeping their hands fixed to their hips, feet shoulder-width apart and bending their knees to a 90-degree angle. A total of three jumps were completed with about 1 minute of recovery between jumps. Jumps were performed on a force plate (HUR FP8, HUR Oy, Kokkola, Finland) and jump height was calculated from impulse (Linthorne, 2001) using Coachtech system. The highest jump was recorded as the current measure of performance. CMJ is a common (Taylor et al., 2012) and valid test for measuring fatigue and explosive power (Bosco et al., 1983) and assessment of CMJ performance using a force platform has shown a high reliability with intraday and interday CVs of 1–6% (Cormack et al., 2008).

Following the CMJ tests, the SRT tests were conducted to evaluate aerobic fitness. Maximal HR values were obtained from prior maximal oxygen uptake tests, and the SRT performed during this study was designed to elicit heart rates (HR) at approximately 90% of maximal HR and thus, significant changes in HR were measurable (Lamberts et al., 2004). The SRT included 4 stages and was 16 minutes in length. The test was performed on a Tunturi GO Run 50 Treadmill (Tunturi Fitness, Flevoland, Netherlands) and speed was standardized (females: 10.0 km/h, males: 11.7 km/h) with inclination increasing every 4 minutes, starting at 2%, then 4%, 7% and 9%. During the SRT, HR was continuously monitored with a HR-monitor (Polar V800, Polar Electro Oy, Kempele, Finland) and HR values were recorded when 15 seconds of each load remained. Prior to the start of the test and during the last 30 seconds of each stage subjects were instructed to provide an overall rating of perceived exertion using Borg's 6–20 point scale (Borg, 1970). Short descriptions of the Borg-Scale were shown to prevent any difficulty in determining their current effort level. After each stage, blood lactate samples were obtained from the fingertip and placed into capillary tubes (20 µL) which included 1-mL hemolyzing solution. The Biosen C-line lactate analyser was used in this study and employs an enzymatic-amperometric method using a chip-sensor technology making it possible to analyse lactate levels within the range of 0.5–40 mmol/l (5–360 mg/dL) with an accuracy less than or equal to 1.5% at 12 mmol/l (EFK Diagnostics Product Catalogue, 2022). For further analysis, a binary model (Tønnessen et al., 2014) was adopted and stage 1 SRT values were analysed to represent low-intensity training values (LIT) and stage 4 SRT values were analysed to represent high-intensity training (HIT). Due to the highly homogenous nature of the group, the utilized protocol was appropriate and submaximal intensities were reached for all subjects (Table 3). Although we do not have validation of this specific protocol, it is a familiar and standardized protocol, which is commonly used as a control test by junior cross-country skiers and biathletes (Kettunen et al., 2021).

2.4. Sleep analysis

Nocturnal HR, HRV (square root of the mean sum of the squared differences between R-R intervals, RMSSD), sleep latency (SL) and sleep duration were measured using a portable bed sensor. This device (EMFIT QS, Emfit OY, Jyväskylä, Finland) consists of a contactless pressure sensor (542 mm × 70 mm × 1.4 mm) that utilizes ballistiocardiography to numerically and graphically present repeated movements (Pinheiro et al., 2010). In a clinical setting, evaluation of this device has shown that it is an acceptable method for continuous monitoring of sleep (Hendriks et al., 2021). In addition, real-life conditions have revealed good agreement ($r = 0.89$–0.90) to laboratory validated reference values and trivial mean bias for nocturnal HR (1.7%, ES = 0.16) and HRV (2.0%, ES = 0.14) [29]. Thus, this device appears to be an effective and convenient method for the sleep variables investigated in this study.

Sleep devices were placed under each subject's mattress near the chest area. The recording process began automatically when body weight was sensed. The device recorded at a sampling rate of 100 Hz, stopping when the subject exited the bed each morning. The subject was unable to detect the presence of the device and data was collected using continuous 3-minute periods. To increase the likelihood of real-life application, the current investigation used HR values that are automatically presented on the user interface of the sleep device. For nocturnal HR, whole night daily average values were used for analysis. For nocturnal HRV, a graphical representation of HRV values was interpreted relative to time, by utilizing RMSSD and the endpoints of the linear line of best fit were selected to represent the average RMSSD values for evening (HRVpm) and morning (HRVam) sleep (Mishica et al., 2022). Daily values were used to calculate weekly averages that were then utilized for analysis. Weekly criteria for all sleep values followed requirements of previous literature that a minimum of three days were needed for weekly HRV values to be obtained (Plews et al., 2014).

2.5. Missing data

The total percentage of missing values was 22% or 302 out of 1334. The percentage of missing values across the variables separately for each timepoint varied and the number of valid measurements for sleep, CMJ and PSS variables is presented in Table 2 and for SRT variables in Table 3. Missing data occurred due to invalid or missing measurements and is from now on assumed to occur at random. For linear mixed-effect modelling, we performed multiple imputation using the mice package (Van Buuren & Groothuis-Oudshoorn, 2011) in R (R Core Team, 2022). We created 50 multiply imputed datasets using 50 iterations. The mixed model parameters were then estimated using each imputed dataset and pooled estimates were obtained using Rubin's rule (Rubin, 2004).

2.6. Statistical analysis

Linear mixed-effect models (LMM) (Pinheiro & Bates, 2000) were used to test the significances of within-sex changes in variables over time. For both sex separately, linear mixed-effect models were fitted using PSS score, jump and running variables as responses and the time as a fixed covariate. To take into account the longitudinal nature of the data, random subject variables were added in mixed-effect models. The analyses were carried using the nlme package (Pinheiro & Bates, 2022) in R. Further, differences between males and females and time-sex interactions were studied by fitting mixed-effect models to combined dataset with sex and sex-time interactions as covariates, respectively. In addition, standardized effect size (Hedge's g) analyses were used to interpret the magnitude of any differences over time within sexes. Notice that as the methods described above were used to test the differences seen in Tables 2 and 3, the models were fitted using the complete data instead of multiply imputed datasets. Finally, to study the effects of sleep variables to PSS, and sleep variables and PSS to jump and running variables, several linear mixed-effect models were fitted to 50 multiply imputed datasets. The sex variable was added in each model to account for changes between males and females. The pooled estimates were obtained using the R package broom.mixed (Bolker & Robinson, 2022).

3. Results

The results for night sleep, nocturnal HRV, perceived stress levels and jump performance, as well as the associated LMM statistics, relative change between measures and effect size obtained over the 4-month period (August–November) are presented in Table 2. Jump performance revealed a slight increase in males (6.1%) with a significant time-sex interaction ($p = 0.005$). In addition, males' sleep HR and perceived stress levels increased significantly (6.3%, $p = 0.004$ and 31.3%, $p = 0.015$, respectively) during the study period. Effects of sex were observed for PSS and jump performance with males obtaining greater jump height and lower PSS than females. PSS responses where significant sex differences were present can be seen in Figure 2. Figure 3 presents an example of individual changes for one male and one female subject that occurred for PSS, RPE, %HRmax and blood lactate concentrations during submaximal running tests during the study period.

The physiological measures obtained during submaximal running treadmill tests and the associated LMM statistics, relative change between measures and effect size are presented in Table 3. Among females, blood lactate levels increased in both stage 1, LIT (32.9%, $p = 0.004$) and stage 4, HIT (23.6%, $p = 0.034$) of submaximal running, whereas blood lactate levels in males decreased and/or remained unchanged during the experimental period. In addition, a significant time-sex interaction was present for lactate during LIT of running tests.

Table 2. Sleep heart rate, duration and latency, perceived level of stress (PSS) and countermovement jump performance (CMJ) by the junior male and female cross-country skiers during the different months of pre-season training.

	August	September	October	November	Time Effect		Aug.- Sept.		Sept.- Oct.		Oct. - Nov.		Aug. - Nov.	
	M, $n = 10$	M, $n = 12$	M, $n = 11$	M, $n = 12$										
Sex	F, $n = 9$	F, $n = 11$	F, $n = 14$	F, $n = 14$	*(df, df) F*	P	%Δ	ES	%Δ	ES	%Δ	ES	%Δ	ES
Sleep HR (bpm)														
M	51.7 ± 5.4	51.2 ± 5.2	51.3 ± 5.5	54.9 ± 6.8	(3, 28) 5.59	0.004*	−1.0	0.09	0.3	0.03	7.0	0.58	6.3	0.53
F	54.5 ± 5.1	53.6 ± 4.4	53.8 ± 5.5	54.5 ± 5.3	(3, 31) 0.95	0.431	−1.6	0.19	0.4	0.04	1.2	0.12	−0.1	0.01
Sleep duration (hrs)														
M	8.5 ± 0.4	8.6 ± 0.7	8.9 ± 0.9	8.7 ± 0.8	(3, 28)1.36	0.274	1.3	0.19	3.5	0.38	−2.1	0.23	2.6	0.35
F	8.3 ± 1.1	8.1 ± 0.8	7.9 ± 1.2	8.7 ± 0.6	(3, 31) 2.23	0.105	−3.1	0.27	−2.0	0.16	9.5	0.81	4.0	0.37
Sleep latency (min)														
M	27.3 ± 2.9	29.2 ± 7.9	26.9 ± 5.0	30.1 ± 7.0	(3, 28) 1.24	0.313	6.7	0.32	−8.0	0.35	11.8	0.52	10.0	0.51
F	33.2 ± 10.1	36.5 ± 10.5	29.7 ± 6.6	31.0 ± 8.9	(3, 31) 1.98	0.137	9.9	0.32	−18.7	0.78	4.4	0.17	−6.8	0.24
HRV_{PM} (RMSSD)														
M	55.1 ± 25.4	56.6 ± 21.7	57.4 ± 20.7	52.2 ± 16.0	(3, 28) 0.82	0.494	2.7	0.06	1.4	0.04	−8.9	0.28	−5.2	0.13
F	58.6 ± 22.0	65.8 ± 20.5	58.7 ± 25.7	69.0 ± 20.3	(3, 31) 0.87	0.467	12.4	0.34	−10.8	0.31	17.5	0.44	17.7	0.49
HRV_{AM} (RMSSD)														
M	69.0 ± 26.7	74.9 ± 25.8	69.2 ± 28.3	69.9 ± 26.6	(3, 28) 1.10	0.367	8.7	0.23	−7.7	0.21	1.0	0.02	1.3	0.03
F	72.2 ± 26.3	73.3 ± 30.1	77.1 ± 22.9	75.9 ± 20.9	(3, 31) 0.24	0.868	1.5	0.04	5.2	0.14	−1.5	0.05	5.1	0.16
PSS score**														
M	10.4 ± 5.9	13.9 ± 9.3	14.3 ± 6.6	13.6 ± 6.5	(3, 23) 4.34	0.015*	34.3	0.46	3.0	0.05	−5.1	0.11	31.3	0.52
F	18.6 ± 11.1	20.6 ± 9.4	18.6 ± 6.1	21.4 ± 8.0	(3, 32) 1.51	0.231	10.9	0.20	−9.7	0.25	15.3	0.40	15.5	0.30
CMJ (cm)**,***														
M	35.3 ± 3.4	35.9 ± 3.1	38.7 ± 3.9	37.5 ± 4.3	(3, 22) 5.78	0.005*	1.6	0.17	7.7	0.80	−3.1	0.29	6.1	0.56
F	29.8 ± 3.2	29.7 ± 4.0	30.2 ± 3.6	30.2 ± 3.4	(3, 30) 0.48	0.698	−0.5	0.04	1.7	0.13	0.0	0.00	1.2	0.11

Also presented here are the within-sex changes over time according to the linear mixed-model (LMM), including the within-sex time effect *F scores*, *degrees of freedom (df)*, *p* values, relative change (%Δ) from week to week and Hedge's *g* effect size (ES).

*Significant effect of time ($p < 0.05$) on the linear mixed model (LMM) for each sex.

**Significant difference in LMM ($p < 0.05$) between the males and females.

***Significant time-sex interaction ($p < 0.05$) observed in LMM for all of the subjects combined.

Table 3. Submaximal running performance, heart rate (HR), blood lactate concentrations (Lac) and rate of perceived exertion (RPE) by the junior male and female cross-country skiers during the different months of pre-season training.

	August	September	October	Time Effect		Aug.- Sept.		Sept.- Oct.		Aug.- Oct.	
	M, *n* = 11	M, *n* = 11	M, *n* = 9								
Sex	F, *n* = 11	F, *n* = 12	F, *n* = 12	*(df, df) F*	P	%Δ	ES	%Δ	ES	%Δ	ES
HR (1% max)											
M	77 ± 5	75 ± 7	71 ± 6	(2, 11) 0.59	0.569	−2.6	0.33	−5.3	0.61	−7.8	1.09
F	77 ± 4	71 ± 22	79 ± 4	(2, 18) 0.87	0.436	−7.8	0.38	11.3	0.51	2.6	0.50
HR 4% max)											
M	90 ± 4	92 ± 6	88 ± 5	(2, 13) 0.78	0.480	2.2	0.39	−4.6	0.72	−2.2	0.44
F	91 ± 2	92 ± 2	93 ± 3	(2, 19) 2.87	0.082	1.1	0.50	1.1	0.39	2.2	0.78
Lac 1 (mmol/L)**											
M	1.8 ± 0.6	1.8 ± 0.5	1.6 ± 0.6	1.24	0.320	−1.1	0.04	−10.4	0.33	−11.4	0.35
F	1.6 ± 0.5	1.8 ± 0.4	2.1 ± 0.5	7.55	0.004*	16.8	0.53	13.8	0.53	32.9	0.98
Lac 4 (mmol/L)											
M	4.5 ± 1.7	5.1 ± 2.1	3.7 ± 1.9	(2, 13) 0.50	0.618	14.5	0.35	−28.4	0.74	−18.0	0.46
F	4.0 ± 1.4	5.2 ± 1.5	5.0 ± 1.4	(2,20) 4.00	0.034*	29.1	0.80	−4.2	0.15	23.6	0.67
RPE 1											
M	10.7 ± 1.2	11.0 ± 1.5	11.8 ± 1.0	(2, 13) 1.72	0.217	2.5	0.20	6.8	0.59	9.5	0.91
F	11.6 ± 0.9	11.5 ± 1.3	11.7 ± 1.1	(2, 20) 0.99	0.907	−0.9	0.09	1.1	0.11	0.3	0.03
RPE 4											
M	15.9 ± 1.5	16.1 ± 1.8	16.3 ± 1.0	(2, 13) 0.48	0.630	1.1	0.11	1.0	0.11	2.1	0.26
F	15.7 ± 1.7	16.1 ± 1.6	16.3 ± 1.6	(2, 20) 0.65	0.533	2.2	0.22	1.6	0.16	3.8	0.37

HR 1 = Percentage of maximal heart rate in stage 1 low-intensity running.
HR 4 = Percentage of maximal heart rate in stage 4 high-intensity running.
Lac 1 = Blood lactate concentration in stage 1, Lac 4 = Blood lactate concentration in stage 4.
RPE 1 = Rate of Perceived Exertion in stage 1; RPE 4 = Rate of Perceived Exertion in stage 4.
Also presented here are the within-sex changes over time according to the linear mixed-model (LMM), including the within-sex time effect *F scores*, *degrees of freedom (df)*, *p* values, relative change (%Δ) from week to week and Hedge's *g* effect size (ES).
*Significant effect of time ($p < 0.05$) on the linear mixed model (LMM) for each sex.
**Significant time-sex interaction ($p < 0.05$) observed in LMM for all of the subjects combined.

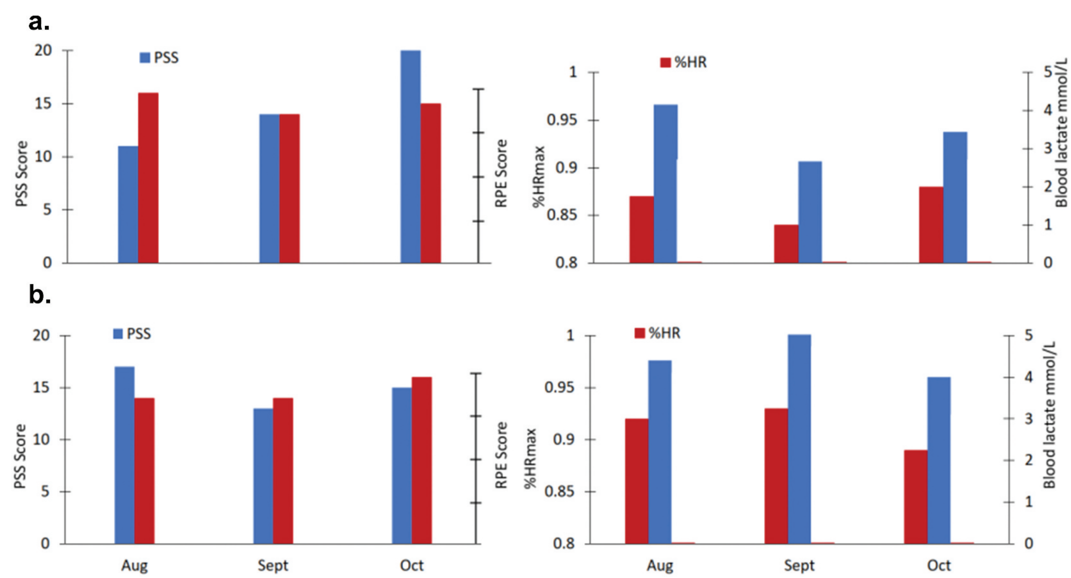

Figure 3. An example of individual changes during a pre-season training period for perceived stress scores (PSS) and rates of perceived exertion (RPE), percentages of maximal heart rate (%HRmax) and blood lactate concentrations during submaximal running in one male (a) and one female (b).

In the total study population, sleep duration revealed a negative association with PSS ($B = -2.79$, $p = 0.01$) and blood lactate concentrations in submaximal running ($B = -0.623$, $p = 0.04$). This implies that for every 1-hour increase in sleep duration the PSS score is estimated to decrease by 2.8 points and lactate is estimated to decrease by 0.62 mmol/L. In addition, a negative relationship was found between SL and CMJ ($B = -0.09$, $p = 0.08$) as well as heart rate during the low-intensity running of SRT ($B = -0.004$, $p = 0.02$) (Tables 4 and 5).

4. Discussion

The major findings here were the negative correlations between perceived stress and sleep duration, between sleep latency and jump performance, and between blood lactate levels during high-intensity running and sleep duration. Moreover, the females displayed considerably higher levels of stress and blood lactate during submaximal running.

In the present study, sleep duration displayed a negative relationship with submaximal blood lactate concentrations

Table 4. Pooled regression estimates of PSS and variables associated with jump performance and their 95% confidence intervals.

	PSS score		Jump	
	B	95% CI	*B*	95% CI
Intercept	28.58*	(0.29, 56.88)	43.49***	(30.44, 56.55)
Sex (F)	5.93*	(1.09, 10.77)	−6.05***	(−8.40, −3.69)
PSS score	-	-	−0.04	(−0.16, 0.09)
Sleep HR	0.17	(−0.25, 0.59)	−0.14	(−0.32, 0.04)
Sleep duration	−2.79**	(−4.95, −0.62)	0.40	(−0.78, 1.58)
Sleep latency	−0.03	(−0.29, 0.23)	−0.09	(−0.20, 0.01)
HRV_{AM}	0.01	(−0.07, 0.09)	0.00	(−0.03, 0.04)

*$p \leq 0.05$, **$p \leq 0.01$, ***$p \leq 0.001$.
HR = heart rate, HRV_{AM} = Morning nocturnal heart rate variability, PSS = perceived stress score.

Table 5. Pooled regression estimates of SRT variables and their 95% confidence intervals.

	Heartrate 1		Heartrate 4		Lactate 1		Lactate 4	
	B	95% CI	*B*	95% CI	*B*	95% CI	*B*	95% CI
Intercept	0.85***	(0.41, 1.30)	0.87***	(0.67, 1.06)	0.74	(−2.21, 3.69)	8.64*	(0.91, 16.37)
Sex (F)	0.04	(−0.02, 0.10)	0.01	(−0.01, 0.04)	0.05	(−0.26, 0.36)	0.12	(−0.84, 1.97)
PSS Score	0.00	(−0.01, 0.00)	0.00	(0.00, 0.00)	−0.01	(−0.03, 0.01)	−0.02	(−0.08, 0.04)
Sleep HR	0.00	(0.00, 0.01)	0.00	(0.00, 0.00)	0.03	(−0.01, 0.06)	0.03	(−0.07, 0.14)
Sleep duration	0.00	(−0.04, 0.03)	0.00	(−0.01, 0.01)	−0.03	(−0.26, 0.20)	−0.62*	(−1.23, −0.02)
Sleep onset	0.00*	(−0.01, 0.00)	0.00	(0.00, 0.00)	0.00	(−0.02, 0.02)	0.01	(−0.05, 0.06)
HRV_{AM}	0.00	(0.00, 0.00)	0.00	(0.00, 0.00)	0.00	(0.00, 0.01)	−0.01	(−0.03, 0.01)

*$p \leq 0.05$, **$p \leq 0.01$, ***$p \leq 0.001$.
HR = heart rate.
HRV_{AM} = Morning nocturnal heart rate variability.
PSS = Perceived stress scale.
SRT = Submaximal running test.

suggesting that a reduction in sleep may influence blood lactate levels. A recent review focused on sleep's effect on youth performance revealed that inadequate sleep results in decreased well-being, increased perceived training loads and decreased performance (Riederer, 2020). Higher lactate levels at a controlled submaximal exercise intensity are often indicative of a decrease in performance (Jacobs, 1986) supporting the idea that the current increase in blood lactate levels may be related to the reduction in sleep. Nevertheless, associations to submaximal lactate levels and performance have not been well established, and therefore, changes in blood lactate concentrations should be evaluated with caution (Swart et al., 2004). The present results also showed that sleep duration was negatively associated with perceived stress levels. Previous research that investigated sleep in junior athletes identified perceived stress as a significant predictor of sleep quality and advised that an athlete's ability to effectively manage perceived stress may help prevent poor sleep (Hrozanova et al., 2019). Although the current study did not focus on direct measures of sleep quality, the impact of sleep duration on competitive performance has been previously investigated (Kirschen et al., 2018) and more time in bed as well as an increase in sleep duration has resulted in improved athletic success (Juliff et al., 2018). Throughout the current training period, athletes continued to maintain the recommended amount of 8 hours of sleep each night (Riederer, 2020) suggesting sleep duration was sufficient. However, the ideal amount of sleep may be individual and some young athletes may need additional sleep (Chaput et al., 2018).

A unique aspect of this study is the continuous analysis of HRV and perceived stress in combination with performance measures. HRV is known to change in response to stress (Kim et al., 2018) yet, we were unable to observe any significant relationships between PSS and nocturnal HRV. Interestingly, females displayed higher nocturnal HRV values which are associated with positive training adaptations (Plews et al., 2013) as well as higher levels of perceived stress which was previously related to a decline in performance (Otter et al., 2015). The current methods may be a possible explanation for these conflicting findings with HRV providing an objective measure of stress that is associated with change in the autonomic nervous system (Kim et al., 2018) and PSS presenting a subjective measure related to individual assessment of stress (Cohen et al., 1983). In addition, athletes were responding to PSS in a retrospective manner (e.g., "in the past month") while HRV was automatically measured each night and weekly average values were used for analysis; therefore, a reduction in associations may exist due to these inconsistencies. This is in line with previous research that showed no changes in nocturnal HR and HRV during a basic endurance training period despite improved endurance performance (Vesterinen et al., 2013). Another factor to consider is that the following measurements occurred during a phase of preseason training when external factors such as competition and travel are reduced. It is likely that athletes may be exposed to different levels of stress during the competition season and frequent monitoring may help prevent a future decline in performance. Therefore, further studies, particularly during a competition season that takes subjective (PSS) as well as objective (HRV) measures of stress into account, should be undertaken.

Sleep latency is an appropriate indicator of sleep quality with sleep latencies ≤30 minutes revealing good sleep quality in both adolescents and adults (Ohayon et al., 2017). In the present study, males displayed latency periods within or below 30 minutes, but females had slightly higher values suggesting that their sleep quality may have been lower (Table 2). Athletes often report low sleep quality indicating improvements in sleep may be an additional tool to help maximize performance (Simpson et al., 2017) and thus, measuring sleep latency may be a applicable way for athletes to monitor sleep quality. We observed a significant negative relationship between sleep latency and CMJ height suggesting the duration of sleep onset may influence jump performance. Although research has shown that sleep restriction impairs vertical jump height (Mah et al., 2019), it is crucial to recognize that the current fluctuation in sleep quality and/or duration occurred naturally and, therefore, was fairly small. Thus, although our findings suggest that when reductions in jump height occur evaluation of individual sleep conditions may be beneficial. More research is needed to better understand associations between sleep quality and jump performance in young athletes.

In the current study, sex differences were found in perceived stress with females consistently showing higher stress scores implying that during the preseason training period females felt a greater amount of perceived stress (Table 2). More specifically, throughout the measurement period, average PSS score was 6.8 points higher in females than in males indicating that females displayed a moderate level of stress versus low stress level in males (Hrozanova et al., 2019). Previous research has uncovered similar findings of sex differences in perceived stress in endurance athletes with females experiencing more stress on various stress-related items prior to a competition (Roberts et al., 2022). Additionally, research investigating university students has consistently revealed that females report a higher level of perceived (Graves et al., 2021) and a greater level of overall stress when compared to male students (Brougham et al., 2009). In the present study, when looking at sex-specific perceived stress responses, significant differences were due to females displaying greater amounts of negative stress; in particular females exhibited increased feelings of "nervousness and stress" and felt they were "unable to control/cope" with present stress (Figure 2). Thus, our findings provide an expansion on previous research that revealed females tend to have a greater risk of elevated stress and anxiety than males (de Visser et al., 2010). Furthermore, males displayed a slightly higher ability to cope with existing stressors. Specifically, males displayed a higher level of perceived confidence and more situations where they felt everything was "going their way". This is in line with earlier findings that showed females reported less control over environmental stressors (Hammermeister & Burton, 2004). However, although females displayed higher levels of perceived stress, previous research has revealed that females utilize adaptive coping strategies (Nqankwo & Onyishi, 2012) and social support systems (Crocker & Graham, 1995) more than males suggesting that females in the current study may have managed the higher levels of stress effectively. Additionally, the supportive environment that a sport academy provides may have additional influence on how athletes in this study were able to balance their total stress load. Thus, future studies should consider reporting if athletes feel they have adequate support and/or effective coping strategies to handle current stress loads so the effect of stress on performance is more clearly observed. Nonetheless, these findings may help coaches to recognize sex differences in perceived stress levels and aid in providing effective strategies and support for young athletes.

With regard to performance, sex differences were observed in jump height and submaximal blood lactate concentrations. Although jump height revealed a slight increase in both males and females, a significant improvement was only visible in males (Table 2). Previous research on endurance runners found that when comparing season best and worst running performances, jump height was significantly higher the week before the season best competition (Balsalobre-Fernández et al., 2014). Additionally, cross-country skiers displayed a positive relationship between jump performance and maximal skiing speed (Stöggl et al., 2011) suggesting that the males in the present study may have been better prepared for the upcoming competition season. However, it's also important to recognize that CMJ performance tests also revealed that jump height and peak power were similar in both male and female cross-country skiers (Gonzalez-Millan et al., 2017) before and after competition suggesting this test may not be the most accurate performance-related measure. Furthermore, similar research focused on CMJ performance during the competition season in junior soccer plays revealed that only trivial changes in CMJ were displayed and reduced training load was not associated with changes in CMJ jump height (Malone et al., 2015).

Throughout the pre-season period, females displayed significant increases in blood lactate concentrations in both low- and high-intensity running of SRT (Table 3). Although it is well known that lactate is highly correlated with performance (Jacobs, 1986) it is important to consider the additional variables and the high individual variability that occurs when interpreting results (Figure 3). We found minimal to no differences in submaximal RPE and increases in HR were within the normal limits of daily variation (Lamberts et al., 2004). In addition, we observed slight improvements in jump performance and HRV which are typically related to increases in performance (Balsalobre-Fernández et al., 2014; Plews et al., 2013). Thus, based on the present findings we cannot conclude whether positive or negative changes occurred during this pre-competition training period.

4.1. Limitations

The present study had some limitations that should be considered. First, sleep variables were collected in individual home environments. Ideally, a controlled environment would provide a more standardized and accurate measure, but the objective was to collect measures that mimic typical everyday use, and therefore, it can also be seen as a strength of this study, but the influence of external factors needs to be considered when interpreting the results. Second, as with many longitudinal studies missing data points occurred due to invalid or missing measurements. Although the current statistical approach was chosen to minimize the influence of missing data, it is still an important factor to acknowledge. Lastly, a performance-related measure and/or a race result would have provided an increased understanding on the relationships that perceived stress may have on young athletes' performance which would have been a valuable addition to take into consideration when interpreting the present results.

5. Conclusion

This study demonstrates that an increase in perceived stress levels in young endurance athletes is associated with diminished sleep duration. It highlights that females experience greater amounts of stress than their male counterparts, and therefore, monitoring of their perceived levels of stress may be beneficial. Accordingly, these results have implications for young athletes preparing for a competition season and perceived stress levels, sleep duration and sleep latency can be easily monitored using simple, non-invasive methods.

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References

Balsalobre-Fernández, C., Tejero-González, C. M., & Del Campo-Vecino, J. (2014). Relationships between training load, salivary cortisol responses and performance during season training in middle and long distance runners. Tauler P, editor. *PLoS One*, *9*(8), e106066. https://doi.org/10.1371/journal.pone.0106066

Baquet, G., Van Praagh, E., & Berthoin, S. (2003). Endurance training and aerobic fitness in young people. *Sports Medicine*, *33*(15), 1127–1143. https://doi.org/10.2165/00007256-200333150-00004

Bolker, B., Robinson, D. (2022). Broom.Mixed: Tidying methods for mixed models. R package version 0294

Borg, G. (1970). Perceived exertion as an indicator of somatic stress. *Scandinavian Journal of Rehabilitation Medicine*, *2*(2), 92–98. https://doi.org/10.2340/1650197719702239298

Bosco, C., Luhtanen, P., & Komi, P. V. (1983, January). A simple method for measurement of mechanical power in jumping. *European Journal of Applied Physiology*, *50*(2), 273–282. https://doi.org/10.1007/BF00422166

Brougham, R. R., Zail, C. M., Mendoza, C. M., & Miller, J. R. (2009, June). Stress, sex differences, and coping strategies among college students. *Current Psychology*, *28*(2), 85–97. https://doi.org/10.1007/s12144-009-9047-0

Chaput, J. P., Dutil, C., & Sampasa-Kanyinga, H. (2018). Sleeping hours: What is the ideal number and how does age impact this? *Nature and Science of Sleep*, *10*, 421–430. https://doi.org/10.2147/NSS.S163071

Cohen, S., Kamarck, T., & Mermelstein, R. (1983). A global measure of perceived stress. *Journal of Health & Social Behavior*, *24*(4), 385–96. https://doi.org/10.2307/2136404

Cormack, S. J., Newton, R. U., McGuigan, M. R., & Doyle, T. L. A. (2008). Reliability of measures obtained during single and repeated countermovement jumps. *International Journal of Sports Physiology and Performance*, *3*(2), 131–144. https://doi.org/10.1123/ijspp.3.2.131

Crocker, P. R. E., & Graham, T. R. (1995). Coping by competitive athletes with performance stress: Gender differences and relationships with affect. *Sport Psychology*, *9*(3), 325–338. https://doi.org/10.1123/tsp.9.3.325

de Visser, L., van der Knaap, L.J., van de Loo, A.J., van der Weerd, C.M.M, Ohl, F., & van den Bos, R. (2010). Trait anxiety affects decision-making differently in healthy men and women: Towards gender-specific endophenotypes of anxiety. *Neuropsychologia*, *48*(6), 1598–1606. https://doi.org/10.1016/j.neuropsychologia.2010.01.027

EFK Diagnostics Product Catalogue. (2022). 17–18. https://www.ekfdiagnostics.com/res/Catalogue-EU-EN-2022.pdf

Gonzalez-Millan, C., Perez-Brunicardi, D., Salinero, J. J., Lara, B., Abián-Vicen, J., Areces, F., Ruiz-Vicente D., Soriano L., & Del Coso J. (2017). Physiological demands of elite cross-country skiing during a real competition. *Journal of Strength & Conditioning Research*, *31*(6), 1536–1543. https://doi.org/10.1519/JSC.0000000000001616

Graves, B. S., Hall, M. E., Dias-Karch, C., Haischer, M. H., Apter, C., & Dalby, A. R. (2021). Gender differences in perceived stress and coping among college students. *PLoS One*, *16*(8), e0255634. https://doi.org/10.1371/journal.pone.0255634

Halson, S. L. (2014). Monitoring training load to understand fatigue in athletes. *Sports Medicine*, *44*(s2), 139–147. https://doi.org/10.1007/s40279-014-0253-z

Hamlin, M. J., Wilkes, D., Elliot, C. A., Lizamore, C. A., & Kathiravel, Y. (2019). Monitoring training loads and perceived stress in young elite university athletes. *Frontiers in Physiology*, *10*, 34. https://doi.org/10.3389/fphys.2019.00034

Hammermeister, J., & Burton, D. (2004). Gender differences in coping with endurance sport stress: Are men from Mars and women from Venus? *Journal of Sport Behavior*, *27*(2), 148–164.

Hendriks, M. M. S., van Lotringen, J. H., Vos van der Hulst, M., & Keijsers, N. L. W. (2021). Bed sensor technology for objective sleep monitoring within the clinical rehabilitation setting: Observational feasibility study. *JMIR MHealth and UHealth*, *9*(2), e24339. https://doi.org/10.2196/24339

Hrozanova, M., Moen, F., & Pallesen, S. (2019). Unique predictors of sleep quality in junior athletes: The protective function of mental resilience, and the detrimental impact of sex, worry and perceived stress. *Frontiers in Psychology*, *10*, 1256. https://doi.org/10.3389/fpsyg.2019.01256

Hynynen, E., Uusitalo, A., Konttinen, N., & Rusko, H. (2006). Heart rate variability during night sleep and after awakening in overtrained athletes. *Medicine & Science in Sports & Exercise*, *38*(2), 313–317. https://doi.org/10.1249/01.mss.0000184631.27641.b5

Jacobs, I. (1986). Blood lactate: Implications for training and sports performance. *Sports Medicine*, *3*(1), 10–25. https://doi.org/10.2165/00007256-198603010-00003

Juliff, L. E., Halson, S. L., Hebert, J. J., Forsyth, P. L., & Peiffer, J. J. (2018). Longer sleep durations are positively associated with finishing place during a national multiday netball competition. *Journal of Strength & Conditioning Research*, *32*(1), 189–194. https://doi.org/10.1519/JSC.0000000000001793

Kettunen, O., Ihalainen, J. K., Ohtonen, O., Valtonen, M., Mursu, J., & Linnamo, V. (2021). Energy availability during training camp is associated with signs of overreaching and changes in performance in young female cross-country skiers. *Biomed Hum Kinet*, *13*(1), 246–254. https://doi.org/10.2478/bhk-2021-0030

Kim, H. G., Cheon, E. J., Bai, D. S., Lee, Y. H., & Koo, B. H. (2018). Stress and heart rate variability: A meta-analysis and review of the literature. *Psychiatry Investigation*, *15*(3), 235–245. https://doi.org/10.30773/pi.2017.08.17

Kirschen, G. W., Jones, J. J., & Hale, L. (2018). The impact of sleep duration on performance among competitive athletes: A systematic literature review. *Clinical Journal of Sport Medicine: Official Journal of the Canadian Academy of Sport Medicine*, *30*(5), 503–512. https://doi.org/10.1097/JSM.0000000000000622.

Lamberts, R. P., Lemmink, K. A. P. M., Durandt, J. J., & Lambert, M. I. (2004). Variation in heart rate during ubmaximal exercise: Implications for monitoring training. *Journal of Strength & Conditioning Research*, *18*(3), 641. https://doi.org/10.1519/1533-4287(2004)18<641:VIHRDS>2.0.CO;2

Lamberts, R. P., Swart, J., Noakes, T. D., & Lambert, M. I. (2011). A novel submaximal cycle test to monitor fatigue and predict cycling performance. *British Journal of Sports Medicine*, *45*(10), 797–804. https://doi.org/10.1136/bjsm.2009.061325

Linthorne, N. P. (2001). Analysis of standing vertical jumps using a force platform. *American Journal of Physics*, *69*(11), 1198–1204. https://doi.org/10.1119/1.1397460

Mah, C. D., Sparks, A. J., Samaan, M. A., Souza, R. B., & Luke, A. (2019). Sleep restriction impairs maximal jump performance and joint coordination in elite athletes. *Journal of Sports Sciences*, *37*(17), 1981–1988. https://doi.org/10.1080/02640414.2019.1612504

Malone, J. J., Murtagh, C. F., Morgans, R., Burgess, D. J., Morton, J. P., & Drust, B. (2015). Countermovement jump performance is not affected during an In-season training microcycle in elite youth soccer players. *Journal of Strength & Conditioning Research*, *29*(3), 752–757. https://doi.org/10.1519/JSC.0000000000000701

Mikkola, J., Rusko, H., Nummela, A., Pollari, T., & Häkkinen, K. (2007). Concurrent endurance and explosive type strength training improves neuromuscular and anaerobic characteristics in young distance runners. *International Journal of Sports Medicine*, *28*(7), 602–611. https://doi.org/10.1055/s-2007-964849

Mishica, C., Kyröläinen, H., Hynynen, E., Nummela, A., & Holmberg, H. C. (2022). Linnamo V. Evaluation of nocturnal vs. morning measures of heart rate indices in young athletes. Mourot L, editor. *PloS One*, *17*(1), e0262333. https://doi.org/10.1371/journal.pone.0262333

Murray, A. (2017). Managing the training load in adolescent athletes. *International Journal of Sports Physiology and Performance*, *12*(s2), S2-42-S2–49. https://doi.org/10.1123/ijspp.2016-0334

Naughton, G., Farpour-Lambert, N. J., Carlson, J., Bradney, M., & Van Praagh, E. (2000). Physiological issues surrounding the performance of adolescent athletes. *Sports Medicine*, *30*(5), 309–325. https://doi.org/10.2165/00007256-200030050-00001

Nqankwo, B. C., & Onyishi, I. E. (2012). Role of self-efficacy, gender and category of athletes in coping with sports stress. *IFE Psychology International Journal*, *20*(2), 94–101.

Nuuttila, O. P., Seipäjärvi, S., Kyröläinen, H., & Nummela, A. (2022). Reliability and sensitivity of nocturnal heart rate and heart-rate variability in monitoring individual responses to training load. *International Journal of Sports Physiology and Performance*, *17*(8), 1296–1303. https://doi.org/10.1123/ijspp.2022-0145

Ohayon, M., Wickwire, E. M., Hirshkowitz, M., Albert, S. M., Avidan, A., & Daly, F. J., et al. (2017). National sleep foundation's sleep quality recommendations: First report. *Sleep Health*, *3*(1), 6–19. https://doi.org/10.1016/j.sleh.2016.11.006

Otter, R., Brink, M., van der Does, H., & Lemmink, K. (2015). Monitoring perceived stress and recovery in relation to cycling performance in female athletes. *International Journal of Sports Medicine*, *37*(1), 12–18. https://doi.org/10.1055/s-0035-1555779

Pinheiro, J., & Bates, D. (2000). Mixed-effects models in S and S-PLUS.

Pinheiro, J., Bates, D. (2022). R Core Team. nlme: Linear and nonlinear mixed effects models. R package version 3.1–161

Pinheiro, E., Postolache, O., & Girão, P. (2010). Theory and developments in an unobtrusive cardiovascular system representation: Ballistocardiography. *The Open Biomedical Engineering Journal*, *4*(1), 201–216. https://doi.org/10.2174/1874120701004010201

Plews, D. J., Laursen, P. B., Meur, Y. L., Hausswirth, C., Kilding, A. E., & Buchheit, M. (2014). Monitoring training with heart-rate variability: How much compliance is needed for valid assessment? *International Journal of Sports Physiology and Performance*, *9*(5), 783–790. https://doi.org/10.1123/ijspp.2013-0455

Plews, D. J., Laursen, P. B., Stanley, J., Kilding, A. E., & Buchheit, M. (2013). Training adaptation and heart rate variability in elite endurance athletes: Opening the door to effective monitoring. *Sports Medicine*, *43*(9), 773–781. https://doi.org/10.1007/s40279-013-0071-8

R Core Team. (2022). *R: A language and environment for statistical computing*. R Found Stat Comput Vienna Austria.

Riederer, M. F. (2020). How sleep impacts performance in youth athletes. *Current Sports Medicine Reports*, *19*(11), 463–467. https://doi.org/10.1249/JSR.0000000000000771

Roberts, S. S., Main, L. C., Condo, D., Carr, A., Jardine, W., Urwin, C., Convit, L., Rahman, S. S., & Snipe, R. M. (2022). Sex differences among endurance athletes in the pre-race relationships between sleep, and perceived stress and recovery. *Journal of Sports Sciences*, *40*(14), 1542–1551. https://doi.org/10.1080/02640414.2022.2091345

Rubin, D. B. (2004). *Multiple imputation for nonresponse in surveys*. Wiley-Interscience. (Wiley classics library).

Saw, A. E., Main, L. C., & Gastin, P. B. (2016). Monitoring the athlete training response: Subjective self-reported measures trump commonly used objective measures: A systematic review. *British Journal of Sports Medicine*, *50*(5), 281–291. https://doi.org/10.1136/bjsports-2015-094758

Simpson, N. S., Gibbs, E. L., & Matheson, G. O. (2017). Optimizing sleep to maximize performance: Implications and recommendations for elite athletes. *Scandinavian Journal of Medicine & Science in Sports*, *27*(3), 266–274. https://doi.org/10.1111/sms.12703

Solomon, M. L., Briskin, S. M., Sabatina, N., & Steinhoff, J. E. (2017). The pediatric endurance athlete. *Current Sports Medicine Reports*, *16*(6), 428–434. https://doi.org/10.1249/JSR.0000000000000428

Stöggl, T., Müller, E., Ainegren, M., & Holmberg, H. C. (2011). General strength and kinetics: Fundamental to sprinting faster in cross country skiing? *Scandinavian Journal of Medicine & Science in Sports*, *21*(6), 791–803. https://doi.org/10.1111/j.1600-0838.2009.01078.x

Swart, J., Jennings, C. L., Swart, J., & Jennings, C. L. (2004). Use of blood lactate concentration as a marker of training status. *South Africa Journal of Sports Medicine*, *16*(3), 1–5.

Taylor, K. L., Chapman, D., Cronin, J., Newton, M., & Gill, N. (2012). Fatigue monitoring in high performance sport: A survey of current trends. *Journal of Australian Strength and Conditioning*, *20*(1), 12–23.

Tønnessen, E., Sylta, Ø., Haugen, T. A., Hem, E., Svendsen, I. S., Seiler, S., & Perc, M. (2014). The road to gold: Training and peaking characteristics in the year prior to a gold medal endurance performance. *PLoS One*, *9*(7), e101796. https://doi.org/10.1371/journal.pone.0101796

Van Buuren, S., & Groothuis-Oudshoorn, K. (2011). Mice: Multivariate imputation by chained equations in *R. Journal of Statistical Software*, *45*(3). https://doi.org/10.18637/jss.v045.i03

Vesterinen, V., Häkkinen, K., Hynynen, E., Mikkola, J., Hokka, L., & Nummela, A. (2013). Heart rate variability in prediction of individual adaptation to endurance training in recreational endurance runners: HRV and endurance training adaptation. *Scandinavian Journal of Medicine & Science in Sports*, *23*(2), 171–180. https://doi.org/10.1111/j.1600-0838.2011.01365.x

Walvekar, S. S. (2015). Study on serum cortisol and perceived stress scale in the police constables. *Journal of Clinical and Diagnostic Research: JCDR*, *9*(2), BC10–4. https://doi.org/10.7860/JCDR/2015/12015.5576

World Medical Association. (2013). World medical association declaration of Helsinki: Ethical principles for medical research involving human subjects. *JAMA*, *310*(20), 2191–4. https://doi.org/10.1001/jama.2013.281053