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Psychological reactions during competitive season and association with sleep among Norwegian junior elite athletes

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Abstract

The current study investigated whether athletes with negatively charged psychological reactivity that includes worry and negative affect experience more sleep disturbance in comparison with athletes whose psychological reactivity involves positive affect. Objective sleep monitoring for a period of 3-4 months was utilized in 32 junior elite athletes. Athletes completed the Positive and Negative Affect Scale, and the Penn State Worry Questionnaire before and after the sleep-monitoring period. Results showed changes and disturbances in sleep as a result of a specific psychological reactivity involving high worry and negative affect. On the other hand, positive affect was associated with normal sleep/wake patterns.

Key words: Positive affect, Negative affect, Sleep, Psychophysiology

Introduction

The ambition of most junior elite athletes is to succeed in elite sport. The ability to withstand pressure and improve performance is key to achieving good results in both training sessions and competitions (Mellalieu, Hanton, & Fletcher, 2006; Woodman & Hardy, 2001). In this greatly competitive environment, only a small handful of athletes experience the success of international sporting excellence (Abernethy, 2008). Thus, the majority of junior elite athletes are not able to meet situational demands of succeeding according to their ambitions. Ultimately, when athletes perceive that they are incapable to meet these demands over time, negative emotions, stress or burnout may occur (Holt & Hogg, 2002; Moen, Myhre, & Sandbakk, 2016; Moen, Myhre, & Stiles, 2016).

Junior elite athletes are often faced with frequent and demanding training sessions, intense and stressful competitions, as well as the challenge of nurturing good relation-

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ships with coaches and teammates. In addition, junior elite athletes are exposed to daily school demands and often tiring social hassles with their peer groups (Compas, Connor-Smith, Saltzman, Thomsen, & Wadsworth, 2001). Importantly, when athletes perceive they lack resources to deal with stress, mental processes related to problem solving in such challenging circumstances have been found to stimulate negative psychological reactions such as worry (Borkovec, Robinson, Pruzinsky, & DePree, 1983; Smith, 1986) and negative affect (Folkman, 2013; Hamama, Ronen, Shachar, & Rosenbaum, 2013).

Therefore, worries about unfulfilled goals and tasks, negative affect responses because of unfulfilled expectations, lack of competitiveness in training and competitions and/or social difficulties with their peer athletes or coaches are all highly relevant, potential stressors for junior elite athletes (Hanton, Fletcher, & Coughlan, 2005; Hinde, 1997; Holt, Hoar, & Fraser, 2005). In demanding circumstances with high stress loads, the restorative processes are especially important for athletes' optimal functioning and prevention of dysfunctional psychological and physiological developments (Goodger, Gorely, Lavallee, & Harwood, 2007). It is widely accepted that sleep has restorative qualities needed for the maintenance of optimal physiological and cognitive functioning, as well as mental well-being. Indeed, research has shown that in the athlete population, sufficient sleep is essential for effective recovery, successful management of fatigue (Hausswirth et al., 2014), and psychological well-being (Sinnerton & Reilly, 1992). Thus, junior elite athletes depend on good quality and quantity sleep for optimal performance and development (Samuels, 2008).

Without sufficient sleep, athletes experience decreases in endurance performance (Oliver, Costa, Laing, Bilzon, & Walsh, 2009), increases in exertion during typical training sessions (Reilly & Piercy, 1994), and unpleasant mood states, including depression, tension, and confusion (Lastella, Lovell, & Sargent, 2012; Reilly & Piercy, 1994; Andrade, Bevilacqua, Coimbra, Pereira, & Brandt, 2016). In addition, sleep deprivation in athletes leads to perception of fatigue being heightened, while vigor decreases significantly (Sinnerton & Reilly, 1992). This is also true for the general population, in which studies of sleep deprivation showed a detrimental influence on cognitive function (Van Dongen, Maislin, Mullington, & Dinges, 2003); mood, specifically subjective vigor, fatigue and depression (Scott, McNaughton, & Polman, 2006); and daytime sleepiness (Carskadon & Dement, 1981).

Interestingly, previous studies have found that worry (Kelly, 2002; Nicassio, Mendlowitz, Fussell, & Petras, 1985; Watts, Coyle, & East, 1994), as well as negative affect (Vandekerckhove & Cluydts, 2010) are associated with sleep disturbance. Furthermore, research has shown that long-term exposure to negative stress, which is related to worry and negative affect, is among the triggering factors of primary insomnia and poor sleep quality (Akerstedt et al., 2012; American Academy of Sleep Medicine, 2005; Dahlgren, Kecklund, & Akerstedt, 2005; Morin, Rodrigue, & Ivers, 2003). Importantly, the majority of the contemporary insomnia models have identified worry as a cause of sleep disturbance (Espie, 2002; Harvey, 2005).

Since empirical research has shown that junior elite athletes are frequently exposed to heavy physical and psychological loads (Moen, Myhre, & Sandbakk, 2016), a good night's sleep that is restorative and energizing both for the body and the mind seems to be of crucial importance in junior elite athletes. Therefore, it is highly relevant to consider the association between psychological (emotional) reactivity and sleep in this population of athletes. The aim of the current study is therefore to investigate the following research question: Do athletes with a negatively charged psychological reactivity that includes worry and negative affect experience more sleep disturbance in comparison with athletes whose psychological reactivity involves positive affect?

Thereby, four specific hypotheses are tested in this research. In a population of junior elite athletes who are experiencing a high stress load, it is hypothesized that:

1. A psychological reactivity that involves high levels of worry and high levels of negative affect will affect sleep negatively.

2. A psychological reactivity that involves high levels of positive affect will affect sleep positively.
3. A disrupted sleep pattern will affect worry and negative affect positively.
4. A normal sleep pattern will affect positive affect positively.

Methods

Participants

Forty junior elite athletes competing at a national and/or international level in their sport participated in this study. Participants were recruited from two Norwegian high schools specialized for elite sports, where athletes must document both talent and ambition to gain admission. A random selection of athletes from these schools was chosen. To be included, athletes had to be in good health, and not be previously diagnosed with any type of sleep disorder. Prior to data collection, participants were given information about why they were selected to participate, and the purpose of the study. Furthermore, participants were informed that all data would be kept confidential, that participation was voluntary, and that the Norwegian Social Science Data Services (NSD) approved the project.

Procedure

Athletes and their coaches received oral information about the study and data collection from the researchers. Participating athletes received an invitation to complete a battery of research materials by email at two time points, before (pre-test) and after (post-test) sleep monitoring, and were given three weeks to complete these. See Figure 1 for an overview of the whole procedure.

Sleep data was collected over a period of three to four months from primo-ultimo February to ultimo May (due to individual start time of data collection). This period corresponds to the second half of the competition season (1. February – 3. April), and the transition to and beginning of the basic preparatory phase of the annual training plan (4. April – 31. May). Only nighttime sleep was monitored and analyzed for this particular study. To secure the quality of the collected data, qualified personnel instructed the participants on how to set up the radar, and provided individual practical and technological guidance if needed. All athletes were instructed to place the radar in the bedroom that they most often used.

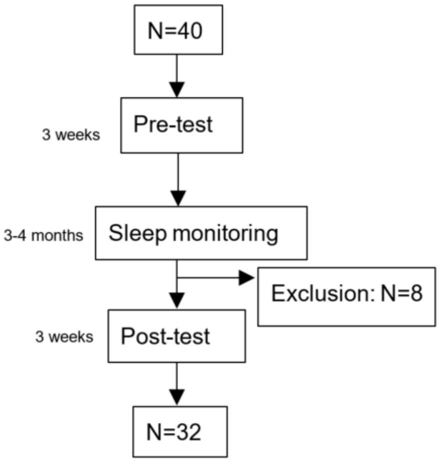

Figure 1. *Flowchart of the procedure applied in the present study, including pre-test, sleep monitoring, post-test, and number of participants*

Materials and instrumentation

Research materials in this study included a survey, questionnaires and the sleep radar. In the survey, athletes had to respond to general variables covering demographics such as age, gender and type of sport. Questionnaires included the Positive and Negative Affect Schedule (PANAS) and the Penn State Worry Questionnaire (PSWQ). These measurements are proven to hold satisfactory validity and reliability. If a Norwegian translation of a scale was not available, as was the case for PANAS, translation-back-translation methods were performed as described by (Duda & Hayashi, 1998). Thus, first the translation was done from English to Norwegian and then back to English to check for potential translation errors.

PANAS

PANAS (Watson, Clark, & Tellegen, 1988) consist of two subscales, one measures positive affect and the other measures negative affect. Athletes were asked to rate the extent to which they have experienced each particular emotion within the last week as an athlete, with reference to a 5-point Likert scale from 1 (not at all) to 5 (very much). In this scale, ten descriptors representing different emotions are used for positive affect (i.e. inspired – strong – enthusiastic) and negative affect (i.e. afraid – distressed – hostile), respectively. The factor structure of the PANAS has previously been supported in a study among young athletes (Crocker, 1997). The PANAS has strong reported validity with measures as general distress and dysfunction, depression, and state anxiety (Moen, Myhre, & Stiles, 2016; Watson, Clark, & Tellegen, 1988; Watson, Clark, & Carey, 1988). Previous studies have shown PANAS to be a valid measure (Crawford & Henry, 2004; Watson, Clark, & Tellegen, 1988). The Cronbach's alphas for this measurement in the current study were .89 (positive affect) and .77 (negative affect) at pre-test, and .87 (positive affect) and .87 (negative affect) at post-test.

PSWQ

To measure the propensity for worry, a Norwegian version of the PSWQ (Meyer, Miller, Metzger, & Borkovec, 1990; Pallesen, Nordhus, Carlstedt, Thayer, & Johnsen, 2006) was used. The Norwegian version of the PSWQ is proven to hold reliability and validity in line with former studies conducted with the original PSWQ (Davey, 1993; Molina & Borkovec, 1994; Pallesen et al., 2006).

PSWQ consists of 16 items, each rated on a five-point Likert scale ranging from 1 (not at all typical) to 5 (very typical). The PSWQ measures the propensity for worry at the present moment. These items measure the pervasiveness (eg. "Many situations make me worry"), excessiveness (eg "I worry all the time"), and uncontrollability (eg "Once I start worrying, I cannot stop") of worry. Athletes were asked to rate how representative each of the different items were for them. Previous research has shown that PSWQ is a valid measurement tool for worry (Brown, Antony, & Barlow, 1992). The Cronbach's alpha for this measurement in the current study was .95 at pre-test, and .94 at post-test.

XeThru sleep radar

To monitor sleep, the present study utilised the radar device XeThru, model X2 (Novelda AS). This is an Impulse Radio-Ultra Wideband Pulse-Doppler radar with an unfiltered bandwidth of 0.9-9.6 GHz. A validation study by Pallesen and colleagues (in press) has shown that the XeThru radar holds moderate to full agreement with polysomnography (PSG) in terms of accuracy, sensitivity and specificity for sleep onset latency, wake after sleep onset and total sleep time.

The sleep algorithm used to calculate sleep measures was the same as used by Pallesen and colleagues (in press) in the validation study of the XeThru X2 device. This algorithm separates sleep and awake in 30 second epochs through the night. Based on that, a number of variables were derived (see Table 1). Data was excluded from analysis if the quality was disturbed due to misplacement of the radar or other technical issues with the instrument. In addition, data is missing from nights when athletes did not sleep in their main bedroom.

Statistical analysis

Statistical analyses were conducted in a two-step procedure using the Dynamic Structural Equation Modeling (DSEM). DSEM is a combination of a multilevel analysis and a time-series analysis with lagged autocorrelations between consecutive measurement points developed for large datasets. The DSEM procedure uses Bayesian estimation.

Firstly, for each sleep parameter named in Table 1, four characteristics were estimated for each participant with the DSEM function of MPLUS 8.0 (Muthén & Muthén, 2017): (b) the mean of the sleep parameter across all recorded nights (e.g., the mean total sleep time); (c) the variance in the sleep parameter for one person during all recorded nights (e.g, how much variation there is in the total sleep time across all nights for an athlete); (d) the inertia in the sleep parameter between consecutive nights. In other words, how much, for example, a night with extremely long or

Table 1. Complete list of sleep variables derived from the sleep algorithm used in the XeThru X2 device by Novelda

Sleep variable	Units	Characteristics of sleep variable
Total sleep time	hh:mm	Total sleep time obtained from sleep onset to wake-up time
Hours of deep sleep	hh:mm	Total amount of time spent in deep sleep (stage N3)
Hours of light sleep	hh:mm	Total amount of time spent in light sleep (stage N1 and N2)
Hours of REM sleep	hh:mm	Total amount of time spent in REM sleep
Wake time in bed	hh:mm	Total amount of time spent awake during the main sleep period, from sleep onset to wake-up time
Sleep onset	hh:mm	Time when start of established sleep was registered. Sleep onset was calculated retrospectively, and defined as the time from when a sleep period of at least 10 mins was established
Wake-up time	hh:mm	Time of last wake-up before absence was registered. Wake-up time was calculated retrospectively, and defined as the time from when no more sleep was registered
Sleep efficiency	%	The percentage of time from sleep onset to wake-up time that was spent asleep

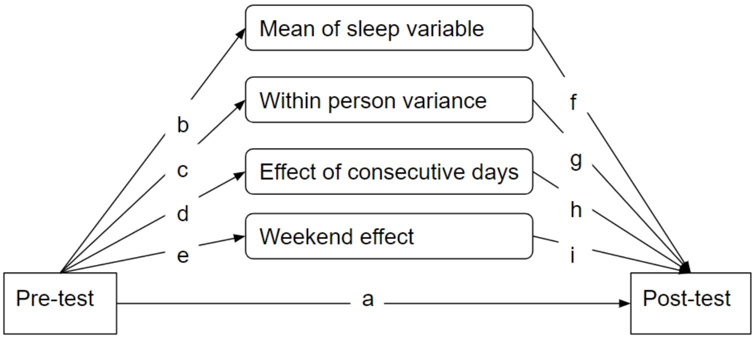

Figure 2. A graphical representation of the relations tested in the DSEM analysis

short sleep affects the sleep time during consecutive nights. This parameter is interesting, because it captures the robustness against disturbances of the sleep patterns of an athlete. Furthermore, (e) the average weekend effect on the sleep parameter (e.g., how much longer does an athlete sleep on average during a night with a weekend day following).

Secondly, for each athlete, a likely value for these four characteristics of the patterns in each sleep parameter was estimated in MPLUS and then exported to SPSS, where these data points were joined with the survey data. In this joined data file, a mediation analysis was conducted where the four characteristics of each sleep parameter were tested for their relation to values of worrying, negative and positive affect measured before (pre-test) and after (post-test) the period the sleeping parameters were analyzed. Figure 2 shows all tested relations in these analyses, which were conducted for eight sleep parameters and worry, negative affect and positive affect, resulting in 24 tests. There was one additional analysis, (a), which investigated the stability of worry, negative affect and positive affect from pre-test to post-test for each participant, using DSEM analysis with MPLUS 8.0. For the analyses, the SPSS mediation analysis plugin PROCESS was used (Hayes, 2013). PROCESS is a regression-based macro that utilizes a series of regression analyses.

Results

Demographics and training data

Due to technical issues with the radar, one of the athletes was excluded from the analyses. Furthermore, 7 athletes had to be excluded from the analyses because they only provided sleep data for single or very few nights, so that no meaningful estimations could be made about their sleep patterns. Thus, 32 athletes were included in the analysis. Out of the 32 athletes, 19 were men and 13 were women. Their mean age was 17.7±0.9 years. For 21 athletes, biathlon was their main sport (13 men and 8 women), whereas cross-country skiing was the main sport for 11 athletes (6 men and 5 women).

Psychological profiles and sleep patterns

Worry and sleep

The mediation analysis (Table 2) showed that between pre- and post-tests, worrying tendencies were highly stable (a). Furthermore, at pre-test, high scores on PSWQ were associated with more hours of sleep in the subsequent months (b), as well as more variability in the hours of deep (c) and light sleep (c) between nights. Participants who scored high on the PSWQ at pre-test had a smaller weekend effect on the hours of deep sleep (e). At post-test, lower PSWQ scores were related to high variability in hours of light sleep (c) in the time period between pre- and post-test. Higher PSWQ values at post-test were related to more wake hours (f), especially at the weekends (i) in the time between pre- and post-test. These higher PSWQ values at post-test were accompanied by less within person variability (g) and inertia (h) of wake hours. Table 2 includes the full mediation analysis for sleep variables as mediators, in relation to worry. To note, coefficients in the table are not standardized, and the calculated p values are based on bias corrected bootstrapped standard errors.

Negative affect and sleep

In the period between pre- and post-test, negative affect was relatively stable (a). There was an effect of negative affect at pre-test on the mean hours of wake-up time (b). In addition, there was an effect of REM sleep inertia on negative affect at post-test (h). The REM inertia variable reports that the amount of REM sleep on one day has an impact on the amount of REM sleep the next day. In this case, the effect of inertia was positive. Apart from these two findings, negative affect and long-term patterns seem not much related in this population of junior elite athletes. The full mediation analysis for sleep variables as mediators in relation to negative affect are presented in Table 3. To note, coefficients in the table are not standardized, and the calculated *p* values are based on bias corrected bootstrapped standard errors.

Positive affect and sleep

The result show that from the time of pre-test to the time of post-test, positive affect was stable (a). The mediation analysis has shown that positive affect is not related to long-term sleeping patterns. Results of full mediation analysis are presented in Table 4. To note, coefficients in the table are not standardized, and the calculated *p* values

Table 2. *Mediation analysis with sleep variables as mediators in relation to worry (PSWQ) at pre- and post-test (N=32)*

	a	b	c	d	e	f	g	h	i
Total sleep	.847§	.215*	.175	.021	.115	.118	-.530	.337	.323
Deep sleep	.839§	.089	.243†	.048	-.066*	.071	-.165	.105	-.208
Light sleep	.801§	.116	.137*	.006	.085	.124	-.727*	-1.012	1.345
REM sleep	.820§	.021	.106	.021	.046	-.302	-.046	.353	.158
Wake	.842§	-.004	.181	-.014	.033	4.519*	-1.403*	-.1960*	6.862*
Start sleep	.783§	-.065	.071	-.029	.023	-.399	-.060	-1.023	-.475
End sleep	.820§	.105	.094	.003	.092	.213	-.542	-.534	.264
Efficiency	.851§	.003	.016	.003	-.001	-5.518	-.986	-.570	-7.620

$^{*}p<.05$, $^{\dagger}p<.01$, $^{\S}p<.001$

Table 3. *Mediation analysis with sleep variables as mediators in relation to negative affect at pre- and post-test (N=32)*

	a	b	c	d	e	f	g	h	i
Total sleep	.706†	.318	.136	-.005	.044	.120	-.565	1.123	.248
Deep sleep	.623*	.281	.241	-.058	-.105	.274	-.229	.310	-.426
Light sleep	.588*	-.021	.077	-.002	.101	-.015	-.291	-1.462	1.034
REM sleep	.724†	.106	.231	.021	.084	-.257	-.424	2.890*	.146
Wake	.759†	-.067	-.221	.001	.005	-.611	.516	.197	-3.035
Start sleep	.685†	.084	.098	-.070	-.056	-.121	-.162	-.603	.513
End sleep	.662†	.235*	.124	-.026	.000	.337	.108	3.127	-.206
Efficiency	.700†	.010	-.039	-.011	.003	-2.391	.750	.923	11.676

$^{*}p<.05$, $^{\dagger}p<.01$

Table 4. *Mediation analysis with sleep variables as mediators in relation to positive affect at pre- and post-test (N=32)*

	a	b	c	d	e	f	g	h	i
Total sleep	.627*	-.044	.045	.040	.131	.150	-.190	-.694	.230
Deep sleep	.564*	-.107	.015	.087	.037	.150	-.450	1.190	-.816
Light sleep	.649*	.094	-.022	-.029	-.022	.235	-.369	2.393	-.121
REM sleep	.582*	.004	.073	.037	.053	.726	-.809	-.325	1.900
Wake	.618*	-.002	-.033	-.001	-.018	-1.000	.010	.955	.221
Start sleep	.600*	-.038	-.159	.064	-.003	.019	.361	1.086	-.952
End sleep	.639*	-.065	.019	.020	.107	-.021	.165	-.688	-.144
Efficiency	.671*	.000	-.023	.045	.005	-.696	-1.401	-.333	-13.732

$^{*}p<.05$

are based on bias corrected bootstrapped standard errors.

Discussion

Junior elite athletes are often exposed to high stress loads (Moen, Myhre, & Sandbakk, 2016). The current population of junior elite athletes was followed over a period of 3 to 4 months during the competition season, and the transition to and beginning of the basic preparatory phase of the annual training plan. This corresponds to a time when athletes go through intense training sessions, in which both the body and the mind are continuously challenged under demanding circumstances. Previous research has shown that the recovery period during times of stress is vulnerable to disturbances (Vandekerckhove & Cluydts, 2010). Insufficient sleep leads to decreases in endurance performance (Oliver, Costa, Laing, Bilzon, & Walsh, 2009), increases in exertion during typical training sessions (Reilly & Piercy, 1994), and unpleasant mood states, including depression, tension, and confusion (Lastella, Lovell, & Sargent, 2012; Reilly & Piercy, 1994; Andrade, Bevilacqua, Coimbra, Pereira, & Brandt, 2016). Therefore, optimal sleep is especially important when the athlete's goal is to ensure optimal physiological and psychological functioning. The aim of the present study was to investigate whether athletes with a negatively charged psychological reactivity that includes worry and negative affect experience more sleep disturbance in comparison with athletes whose psychological reactivity involves positive affect.

This study utilized objective sleep assessment of athletes' sleep patterns, and validated questionnaires to assess worry and affect. Thereby, four specific hypotheses were tested.

In a population of junior elite athletes who are experiencing a high stress load, it was hypothesized that, firstly, disturbed sleep is associated with a specific psychological reactivity that involves high levels of worry and high levels of negative affect. The second hypothesis tested in this study postulated that in the present population of junior elite athletes who are experiencing a high stress load, normal sleep is associated with a specific psychological reactivity that involves high levels of positive affect. The third hypothesis postulated that a disturbed sleep pattern is associated with higher levels of worry and negative affect, while the fourth hypothesis postulated that a normal sleep pattern is associated with lower levels of worry and higher levels of positive affect.

The first hypothesis was partially confirmed. Results found that those with high worry at pre-test slept more in the subsequent months, and that those with high negative affect woke up later in the mornings. This might point to an increased need for recovery when worry and/or negative affect are heightened. In addition, the association between high worry and longer sleep was accompanied by a significant variability in the hours of light and deep sleep between nights. This finding points to the worsening of sleep quality and thus supports the first hypothesis.

It is compelling that despite more hours of sleep, athletes' cycling through sleep stages was highly variable. Previous research has found that acute bouts of exercise in adolescents lead to increased deep sleep and decreased light sleep (Dworak et al., 2008), a finding which is in accord with the results presented here. The cycling between light and deep sleep throughout the night is one of the principal features of normal sleep, and previous research has shown that a disturbance in the alternations of these stages may have detrimental effects on daytime functioning (Laffan, Caffo, Swihart, & Punjabi, 2010). However, this study did not evaluate athletes' perception of sleep and its influence on daytime functioning, so the impact of the significant variability in the hours of light and deep sleep between nights remains to be determined by future research.

Furthermore, those with high worry at pre-test experienced a smaller weekend effect on the hours of deep sleep in the subsequent months. The weekend effect describes how much longer, on average, an athlete sleeps during the weekend than during the week. Thus, this finding shows that the variability in the hours of deep sleep during the week when compared with the weekend was significantly smaller in those with high worry. This finding further points to changes and variability in sleep parameters because of high worry, which supports the first hypothesis.

The third hypothesis was also partly confirmed, as high worry at post-test was associated with more wake hours, especially at weekends, in the period between pre- and post-test. This finding was accompanied by less within person variability and inertia of wake hours. Thus, high values of wake hours that are consistent (less within person variability) but that do not necessarily cause spillover effects (less inertia), lead to high levels of worry. In other words, these findings suggest that consistently high wake hour values lead to subsequently higher scores of worry. Staying up late into the night, or the inability to fall asleep for prolonged periods are both detrimental practices. Respectively, they point to inappropriate sleep hygiene and risk for the development of sleep-onset insomnia (Gellis & Lichstein, 2009). In fact, worry is today considered a major precipitant of sleep disturbances in nearly all insomnia models (Espie, 2002; Harvey, 2005). Worry precipitates sleep disturbances by inducing cognitive arousal - a state of cognitive hyper vigilance, characterized by the inability to repress mental activity while attempting to sleep (Harvey, Tang, & Browning, 2005).

Further evidence for the support of the third hypothesis involves the association between post-test negative affect and REM inertia. In this case, athletes for whom short periods of REM sleep on one night carry over to the following night are more inclined to experiencing negative affect later. Therefore, a variable and disturbed sleep pattern, exemplified here by periods of REM sleep inertia, is associated with negative affect. Interestingly, negative affect has been widely acknowledged a frequent cause for both subjective and objective sleep disturbance (Vandekerckhove & Cluydts, 2010).

In addition, high variability in light sleep in the duration between pre- and post-test was associated with lower worry at post-test. This finding, at a first glance, refutes the third hypothesis. It is hereby suggested that this association between high variability in light sleep with lower worry at post-test may be related to the effects of exercise on light sleep. Previous research has found that regular exercise decreases light sleep (stage N1) in adolescents (Mendelson et al., 2016). Similarly, the subjective perception of greater exertion during exercise was related to decreased light sleep in another study (Brand et al., 2014). Therefore, it is likely that the observed variability in light sleep in those with low worry is associated to the effects of exercise on sleep.

The second and fourth hypotheses were fully supported. Results showed that athletes with a specific psychological reaction of positive affect have normal sleep patterns in the months subsequent to pre-testing, and no variations in the measured sleep variables were found. This shows that normal sleep is associated with a specific psychological reactivity that involves high levels of positive affect.

Limitations

One of the limitations in this study concerns the use of the XeThru sleep radar. Only 3 sleep variables derived from the XeThru sleep radar have been validated against PSG for accuracy, sensitivity and specificity. These were sleep onset latency, wake after sleep onset and total sleep time, and a moderate to-full agreement with PSG has been shown (Pallesen et al, 2018. However, the sleep radar has not been validated for the remaining sleep variables analyzed in this study: hours of light sleep, hours of deep sleep, hours of REM sleep, and wake hours. The XeThru radar is under constant development, and algorithms are expected to be improved so that the aforementioned variables concerning sleep stages will be validated for accuracy, sensitivity and specificity against PSG with satisfactory results.

To unobtrusively monitor sleep, the method of choice typically falls on actigraphy. Actigraphy has been validated for its ability to correctly identify sleep and wake, but results show a trend of sleep overestimation and wake time underestimation (Ancoli-Israel et al., 2003). Actigraphy cannot reliably detect light, deep and REM sleep, nor wake hours during the sleep period. Therefore, we deemed our choice of the XeThru sleep radar reasonable and at least as reliable as actigraphy.

Another limitation in the current study is the distance in time between the psychological data and the sleep data. The current study measures affect tendencies during the last week and sleep was measured over months. To investigate the relationship between affect and sleep quality, affect should be measured just prior to sleep and/or right after sleep, on a daily basis. That would subsequently allow for multi-level analysis of the results at between and within persons level, and for elucidation of the immediate effects of sleep on psychological variables (and vice versa). However, even though the current study indicates possible relationships, future studies should take such limitations into considerations and collect psychological data more frequently. The current study also includes a small sample size and generalization to junior elite athletes in general cannot be done.

Conclusion

The results in the current study with 32 junior elite athletes indicate that psychological reactivity that includes high levels of worry and high levels of negative affect can negatively affect sleep. Specifically, the high levels of worry and negative affect lead to disturbed sleep with significant variability in objectively measured sleep parameters. High worry at pre-test lead to increased total sleep time, significant variability in the cycling between light and deep sleep, later morning awakenings, and reduced variability in the hours of deep sleep during the week when compared with the weekend. Such variability in sleep parameters might point to an increased need for recovery when worry and/or negative affect are heightened. Whenever abnormalities in some of the principal features of normal sleep occur, athletic recovery as well as daytime physiological and psychological functioning of athletes may be at risk.

Furthermore, consistently high wake hour values lead to subsequently higher scores of worry at post-test, and consistently high wake hour values as well as short REM sleep inertia lead to subsequently higher scores of negative affect. These results are alarming, as worry has been linked to insomnia via cognitive hyper arousal, and negative affect has been associated with both subjective and objective sleep disturbance.

Interestingly, sleep patterns of junior elite athletes that experience high levels of positive affect are unaffected and normal. This study offers evidence that high levels of worry and negative affect are objectively detrimental to junior elite athletes' sleep. Poor sleep in this population may have long-standing and far-reaching consequences, including worsened performance, ineffective recovery, poor management of fatigue and psychological well-being.

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References

Abernethy, B. (2008). Introduction: Developing expertise in sport-how research can inform practice. In D. Farrow, J. Baker, & C. MacMahon (Eds.), *Developing Sport Expertise: Researchers and Coaches Put Theory into Practice* (pp. 1-14). Abingdon, Oxon: Routledge.

Akerstedt, T., Orsini, N., Petersen, H., Axelsson, J., Lekander, M., & Kecklund, G. (2012). Predicting sleep quality from stress and prior sleep — A study of day-to-day covariation across six weeks. *Sleep Med*, **13**(6), 674-679. doi:10.1016/j.sleep.2011.12.013

American Academy of Sleep Medicine. (2005). International classification of sleep disorders, *Diagnostic and coding manual* (2nd ed.). Westchester, IL: American Academy of Sleep Medicine.

Ancoli-Israel, S., Cole, R., Alessi, C., Chambers, M., Moorcroft, W., & Pollak, C. P. (2003). The role of actigraphy in the study of sleep and circadian rhythms. *Sleep: Journal of Sleep and Sleep Disorders Research*, **26**(3), 342-392. doi: 10.1093/sleep/26.3.342

Andrade, A., Bevilacqua, G. G., Coimbra, D. R., Pereira, F. S., & Brandt, R. (2016). Sleep quality, mood and performance: A study of elite Brazilian volleyball athletes. *Journal of sports science & medicine*, **15**(4), 601.

Borkovec, T. D., Robinson, E., Pruzinsky, T., & DePree, J. A. (1983). Preliminary exploration of worry: Some characteristics and processes. *Behav Res Ther*, **21**(1), 9-16.

Brand, S., Kalak, N., Gerber, M., Kirov, R., Puhse, U., & Holsboer-Trachsler, E. (2014). High self-perceived exercise exertion before bedtime is associated with greater objectively assessed sleep efficiency. *Sleep Med*, **15**(9), 1031-1036. doi: 10.1016/j.sleep.2014.05.016

Brown, T. A., Antony, M. M., & Barlow, D. H. (1992). Psychometric properties of the Penn State Worry Questionnaire in a clinical anxiety disorders sample. *Behaviour Research and Therapy*, **30**(1), 33-37. doi: 10.1016/0005-7967(92)90093-V

Carskadon, M. A., & Dement, W. C. (1981). Cumulative effects of sleep restriction on daytime sleepiness. *Psychophysiology*, **18**(2), 107-113. doi: 10.1111/j.1469-8986.1981.tb02921.x

Compas, B. E., Connor-Smith, J. K., Saltzman, H., Thomsen, A. H., & Wadsworth, M. E. (2001). Coping with stress during childhood and adolescence: Problems, progress, and potential in theory and research. *Psychol Bull*, **127**(1), 87-127. doi: 10.1037/0033-2909.127.1.87

Crawford, J. R., & Henry, J. D. (2004). The Positive and Negative Affect Schedule (PANAS): Construct validity, measurement properties and normative data in a large non-clinical sample. *British Journal of Clinical Psychology*, **43**(3), 245-265. doi: 10.1348/0144665031752934

Crocker, P. R. (1997). A confirmatory factor analysis of the

Positive Affect Negative Affect Schedule (PANAS) with a youth sport sample. *Journal of Sport and Exercise Psychology*, **19**(1), 91-97. doi: 10.1123/jsep.19.1.91

Dahlgren, A., Kecklund, G., & Akerstedt, T. (2005). Different levels of work-related stress and the effects on sleep, fatigue and cortisol. *Scand J Work Environ Health*, **31**(4), 277-285. doi:10.5271/sjweh.883

Davey, G. C. (1993). A comparison of three worry questionnaires. *Behav Res Ther*, **31**(1), 51-56. doi: 10.1016/0005-7967(93)90042-S

Duda, J., & Hayashi, C. (1998). Measurement issues in cross-ultural research within sport and exercise psychology. In J. L. Duda (Ed.), *Advances in Sport and Exercise Psychology Measurement* (pp. 471–483). Morgantown, WV: Fitness Information Technology.

Dworak, M., Wiater, A., Alfer, D., Stephan, E., Hollmann, W., & Strüder, H. K. (2008). Increased slow wave sleep and reduced stage 2 sleep in children depending on exercise intensity. *Sleep Medicine*, **9**(3), 266-272. doi: 10.1016/j.sleep.2007.04.017

Espie, C. A. (2002). Insomnia: Conceptual issues in the development, persistence, and treatment of sleep disorder in adults. Annu Rev Psychol, **53**, 215-243. doi: 10.1146/annurev.psych.53.100901.135243

Folkman, S. (2013). Stress: appraisal and coping. In M. Gellman, J. R. Turner (Eds.), *Encyclopedia of behavioral medicine* (pp. 1913-1915). New York: Springer.

Gellis, L. A., & Lichstein, K. L. (2009). Sleep hygiene practices of good and poor sleepers in the United States: an internet-based study. *Behav Ther*, **40**(1), 1-9. doi:10.1016/j.beth.2008.02.001

Goodger, K., Gorely, T., Lavallee, D., & Harwood, C. (2007). Burnout in sport: A systematic review. *Sport Psychologist*, **21**(2), 127-151. doi: 10.1123/tsp.21.2.127

Hamama, L., Ronen, T., Shachar, K., & Rosenbaum, M. (2013). Links between stress, positive and negative affect, and life satisfaction among teachers in special education schools. *Journal of Happiness Studies*, **14**(3), 731-751. doi: 10.1007/s10902-012-9352-4

Hanton, S., Fletcher, D., & Coughlan, G. (2005). Stress in elite sport performers: a comparative study of competitive and organizational stressors. *J Sports Sci*, **23**(10), 1129-1141. doi: 10.1080/02640410500131480

Harvey, A. G. (2005). Unwanted Intrusive Thoughts in Insomnia. In D. A. Clark (Ed.), *Intrusive thoughts in clinical disorders: Theory, research, and treatment* (pp. 86-118). New York, NY: Guilford Press.

Harvey, A. G., Tang, N. K., & Browning, L. (2005). Cognitive approaches to insomnia. *Clin Psychol Rev*, **25**(5), 593-611. doi: 10.1016/j.cpr.2005.04.005

Hausswirth, C., Louis, J., Aubry, A., Bonnet, G., Duffield, R., & Y, L. E. M. (2014). Evidence of disturbed sleep and increased illness in overreached endurance athletes. Med Sci Sports Exerc, 46(5), 1036-1045. doi: 10.1249/MSS.0000000000000177

Hayes, A. F. (2013). *Introduction to Mediation, Moderation, and Conditional Process Analysis: A Regression-Based Approach*. New York, NY: The Guilford Press.

Hinde, R. A. (1997). *Relationships: A Dialectical Perspective*. Hove, U.K.: Psychology Press.

Holt, N. L., Hoar, S., & Fraser, S. N. (2005). How does coping change with development? A review of childhood and adolescence sport coping research. *European Journal of Sport Science*, **5**(1), 25-39. doi: 10.1080/17461390500076915

Holt, N. L., & Hogg, J. M. (2002). Perceptions of stress and coping during preparations for the 1999 women's soccer world cup finals. *The Sport Psychologist*, **16**(3), 251-271. doi: 10.1123/tsp.16.3.251

Kelly, W. E. (2002). Worry and sleep length revisited: worry, sleep length, and sleep disturbance ascribed to worry. *J Genet Psychol*, **163**(3), 296-304. doi: 10.1080/00221320209598685

Laffan, A., Caffo, B., Swihart, B. J., & Punjabi, N. M. (2010). Utility of sleep stage transitions in assessing sleep continuity. *Sleep*, **33**(12), 1681-1686. doi: 10.1093/sleep/33.12.1681

Lastella, M., Lovell, G. P., & Sargent, C. (2014). Athletes' precompetitive sleep behaviour and its relationship with subsequent precompetitive mood and performance. *European Journal of Sport Science*, **14**, 123-130. doi: 10.1080/17461391.2012.660505

Mellalieu, S. D., Hanton, S., & Fletcher, D. (2006). A competitive anxiety review: Recent directions in sport psychology research. In S. Hanton & S. D. Mellalieu (Eds.), *Literature Reviews in Sport Psychology*. Hauppauge, New York: Nova Science Publishers, Inc.

Mendelson, M., Borowik, A., Michallet, A. S., Perrin, C., Monneret, D., Faure, P., ... Flore, P. (2016). Sleep quality, sleep duration and physical activity in obese adolescents: effects of exercise training. *Pediatr Obes*, **11**(1), 26-32. doi:10.1111/ijpo.12015

Meyer, T. J., Miller, M. L., Metzger, R. L., & Borkovec, T. D. (1990). Development and validation of the Penn State Worry Questionnaire. *Behav Res Ther*, **28**(6), 487-495. doi: 10.1016/0005-7967(90)90135-6

Moen, F., Myhre, K., & Sandbakk, Ø. (2016). Psychological determinants of burnout, illness and injury among elite junior athletes. *The Sport Journal*. Retrieved from http://thesportjournal.org/article/psychological-determinants-of-burnout-illness-and-injury-among-elite-junior-athletes/

Moen, F., Myhre, K., & Stiles, T. C. (2016). An Exploration about how Passion, Perceived Performance, Stress and Worries Uniquely Influence Athlete Burnout. *Journal of Physical Education*, **3**(1), 88-107. doi: 10.15640/jpesm.v3n1a7

Molina, S., & Borkovec, T. D. (1994). The Penn State Worry Questionnaire: Psychometric properties and associated characteristics. In G. C. L. Davey & F. Tallis (Eds.), *Wiley series in clinical psychology. Worrying: Perspectives on theory, assessment and treatment* (pp. 265-283). Oxford, England: John Wiley & Sons.

Morin, C. M., Rodrigue, S., & Ivers, H. (2003). Role of stress, arousal, and coping skills in primary insomnia. *Psychosom Med*, **65**(2), 259-267. doi: 10.1097/01.PSY.0000030391.09558.A3

Muthén, L., & Muthén, B. (2017). *Mplus User's Guide, 8th ed.* Los Angeles, CA: Muthén & Muthén.

Nicassio, P. M., Mendlowitz, D. R., Fussell, J. J., & Petras, L. (1985). The phenomenology of the pre-sleep state: the development of the pre-sleep arousal scale. *Behav Res Ther*, **23**(3), 263-271. doi: 10.1016/0005-7967(85)90004-X

Oliver, S. J., Costa, R. J., Laing, S. J., Bilzon, J. L., & Walsh, N. P. (2009). One night of sleep deprivation decreases treadmill endurance performance. *Eur J Appl Physiol*, **107**(2), 155-161. doi:10.1007/s00421-009-1103-9

Pallesen, S., Nordhus, I. H., Carlstedt, B., Thayer, J. F., & Johnsen, T. B. (2006). A Norwegian adaptation of the Penn State Worry Questionnaire: factor structure, reliability, validity and norms. *Scand J Psychol*, **47**(4), 281-291. doi:10.1111/j.1467-9450.2006.00518.x

Pallesen, S., Grønli, J., Myhre, K., Moen, F., Bjorvatn, B., Hanssen, I., & Heglum, H. S. A. A Pilot Study of Impulse Radio Ultra Wideband Radar Technology as a New Tool for Sleep Assessment. *Journal of Clinical Sleep Medicine*. in press.

Reilly, T., & Piercy, M. (1994). The effect of partial sleep deprivation on weight-lifting performance. *Ergonomics*, **37**(1), 107-115. doi: 10.1080/00140139408963628

Samuels, C. (2008). Sleep, recovery, and performance: the new frontier in high-performance athletics. *Neurol Clin*, **26**(1), 169-180; ix-x. doi:10.1016/j.ncl.2007.11.012

Scott, J. P., McNaughton, L. R., & Polman, R. C. (2006). Effects of sleep deprivation and exercise on cognitive, motor performance and mood. *Physiol Behav*, **87**(2), 396-408. doi:10.1016/j.physbeh.2005.11.009

Sinnerton, S., & Reilly, T. (1992). Effects of sleep loss and time of day in swimmers. *Biomechanics and medicine in swimming: swimming science VI*, 399-404.

Smith, R. E. (1986). Toward a cognitive-affective model of athletic burnout. *Journal of Sport Psychology*, **8**(1), 36-50. doi: 10.1123/jsp.8.1.36

Van Dongen, H. P., Maislin, G., Mullington, J. M., & Dinges, D. F. (2003). The cumulative cost of additional wakefulness: dose-response effects on neurobehavioral functions and sleep physiology from chronic sleep restriction and total sleep deprivation. *Sleep*, **26**(2), 117-126. doi: 10.1093/sleep/26.2.117

Vandekerckhove, M., & Cluydts, R. (2010). The emotional brain and sleep: an intimate relationship. *Sleep Med Rev*, **14**(4), 219-226. doi:10.1016/j.smrv.2010.01.002

Watson, D., Clark, L. A., & Carey, G. (1988). Positive and negative affectivity and their relation to anxiety and depressive disorders. *Journal of Abnormal Psychology*, **97**(3), 346-353. doi: 10.1037/0021-843X.97.3.346

Watson, D., Clark, L. A., & Tellegen, A. (1988). Development and Validation of Brief Measures of Positive and Negative Affect - the Panas Scales. *Journal of Personality and Social Psychology*, **54**(6), 1063-1070. doi: 10.1037/0022-3514.54.6.1063

Watts, F. N., Coyle, K., & East, M. P. (1994). The contribution of worry to insomnia. *Br J Clin Psychol*, **33**(Pt 2), 211-220. doi: 10.1111/j.2044-8260.1994.tb01115.x

Woodman, T., & Hardy, L. (2001). A case study of organizational stress in elite sport. *Journal of Applied Sport Psychology*, **13**(2), 207-238. doi: 10.1080/104132001753149892