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Inconsistency between objective and subjective comparisons of sleep quality are found between sea level and moderate terrestrial altitude (2,320m) in high-performance swimmers

Sleep quality comparison between sea level and altitude in high-performance swimmers

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Abstract

It is popular for high-performance athletes to attend training camps at natural moderate altitude (1800-2500m), which may have direct and indirect effects on the quantity and quality of sleep athletes obtain. This can potentially influence the ability to maximise training responses and optimise recovery from exercise. This study aimed to compare objective and subjective markers of sleep quality between sea level (SL) and moderate altitude (ALT) in a sample of fourteen (male n=5, female n=9) high-performance collegiate swimmers. Sleep was objectively (wristwatch actigraphy) and subjectively (Athlete Sleep Screening Questionnaire; ASSQ) assessed at SL and an ALT of 2,320m. A significant increase ($p = 0.028$, $d = 0.76$) in the 'sleep difficulty score' calculated from the ASSQ was identified from SL (4.9 ± 1.7 au) to ALT (6.6 ± 2.3 au), with a greater number of the swimmers judged to have a more severe clinical sleep problem at ALT. Of the seven sleep characteristics assessed objectively, there were no significant differences identified between the two environments. Sleep disruption was found to substantially improve following rest/recovery days while at ALT. While this study highlights possible inconsistencies between objective and subjective measures of sleep quality while at ALT, any suggestion of reduced sleep quality should be considered seriously. Practically, the present study demonstrates the importance of, at altitude, using both objective and subjective measures to monitor athlete sleep quality, and ensuring training schedules are carefully periodised, incorporating rest or recovery days within intense training blocks for optimal sleep quality to be achieved.

Key Words – hypoxia, training, actigraphy, recovery, athletes

Highlights

- High-performance collegiate swimmers reported significantly reduced subjective sleep quality at moderate altitude (2,320m) compared to their native sea level home environment.
- Potential inconsistencies between objective and subjective measures of sleep quality while at altitude highlight the need for use of multiple methods of sleep monitoring.
- Substantial improvements in the degree of sleep disruption at altitude appear to be related to rest or recovery days in the periodised training schedule.

Introduction

The use of training camps at moderate terrestrial altitude (ALT) (between 1800 and 2500m)[1] has become commonplace for high-performance endurance athletes in recent decades.[2] Training is completed in the hypoxic environment offered by natural ALT in an attempt to enhance specific physiological and neuromuscular characteristics that can lead to enhanced performance on return to SL.[3] While ALT training can be beneficial to athlete performance,[4] there are a number of risks attached to attending training camps at natural ALT. Examples include jetlag and travel fatigue from the travel to the camp, a reduction in the possible training intensity due to the hypoxic environment, and an increased risk of injury and illness, which may negate the targeted positive adaptations elicited by the training intervention.[5] A further substantial potential risk to athletes associated with training at ALT is a compromised quality of sleep.[6]

Sleep has been identified as a vital factor for achieving an optimal balance between training and recovery in athletes.[7] Both the quality and duration of sleep periods are determinants of the ability to maximise training responses and optimise physiological and psychological recovery from exercise.[8] ALT is hypothesised to interfere with sleep quality due to the respiratory alkalosis caused by a hypoxia-induced hyperventilation, leading to a decrease in hypoxaemia during sleep. This reduces the respiratory drive and so results in apnoeic periods.[9] A range of electroencephalogram (EEG) studies have identified that this disturbed breathing may be responsible for the decrease in slow wave sleep and greater degree of sleep fragmentation that has been reported in individuals residing at ALTs greater than 2000m,[10] the typical range for the majority of moderate ALT training camps[1]. While the acute left-shift of the oxygen-dissociation curve caused by respiratory alkalosis can be corrected within a few days to a week in fully acclimatised individuals, this may take longer in those athletes not familiar with altitude training interventions.[11]

Optimal recovery is essential during periods of intensified training load, such as training camps at ALT.[12] When the quality and/or duration of sleep an athlete obtains is reduced acutely, there is a higher physiological demand for exercise, such as elevated heart rate, ventilation and respiratory rate, leading to an increased perception of fatigue and decreased capacity for training.[13] When athletes experience a sustained period of disturbed sleep, it has been identified that the resulting imbalance in nervous system activity may lead to an over-trained like state.[13] Additionally, decreased neuromuscular recovery may occur as the result of a sleep quality driven hormonal imbalance.[7] Finally, chronic disturbed sleep can lead to a number of psychological issues in athletes, such as increased anxiety, stress and poor decision making.[7] It is therefore critically important to develop a deeper understanding of the effects that temporary residence at moderate ALT has on the sleep of high-performance athletes, and how this environment may cause sleep quality to differ from SL.

Previously, there have been numerous anecdotal accounts of disturbed and restless sleep from athletes while in hypoxia, related to periodic breathing.[9] In a paper where the perceptions of elite athletes and support staff towards ALT training were gathered, both reported that they had experienced disturbed sleep at ALT compared to sea-level.[14] Roach and colleagues[15] identified objective evidence of reduced sleep quality in international youth team-sport athletes at ALT, reporting both acute and chronic sleep disruption. In a companion paper, Sargent and colleagues[16] found that rapid eye movement (REM) sleep was the worst affected stage of sleep at ALT, with 50% of their sample also exhibiting impaired breathing during sleep. However, these results were found at high ALTs (i.e. >3500m). The implications for sleep at moderate ALTs, at which traditional ALT training camps are conducted, are much more ambiguous[17]. Lastella and colleagues[18] identified a trend towards a decreased subjective sleep quality in international under-20 Australian team sport athletes while at moderate ALT compared to SL, however, this stabilised after 5 days following arrival. The authors therefore concluded the findings were likely to be the result of travel fatigue, jetlag and sleeping in a new environment rather than the ALT "per se". More recently, Hrozanova and colleagues[19] used a microwave Doppler radar for daily measurement of senior national-team endurance athlete sleep characteristics, at SL and an ALT of 1800m. The authors found that total sleep time ($p=0.036$) and light sleep ($p<0.001$) decreased at ALT, while deep sleep ($p<0.001$) and respiration rate ($p=0.020$) increased compared to baseline measures, being the first study to document changes in sleep between SL and a training camp at altitude in elite endurance athletes.[19]

Despite uncertainty in the causal mechanisms, the possibility of impaired sleep quality at moderate ALTs has implications for recovery and performance in training, ultimately impacting on the overall success of an ALT intervention.[9] Due to the lack of controlled research and over-reliance on anecdotal reports in this area, a study reporting the effects of moderate ALT on both the objective and subjective sleep quality of high-performance athletes was required. Therefore, we aimed to compare both subjective and objective markers of sleep quality in high-performance collegiate swimmers between their native SL environment and during a moderate ALT training camp at 2,320m.

Methods

Study Design

The present study used a single-cohort repeated-measures intervention design to compare both objective and subjective markers of sleep quantity and quality between SL and moderate ALT in high-performance collegiate swimmers. The participants completed a three-week terrestrial 'live-high, train-high' (LHTH) ALT training camp in Sierra Nevada, Spain (2,320m) in January 2020, marking the beginning of the long-course (50m pool) half of the swimming season. The purpose of the training camp was to induce specific physiological and neuromuscular adaptations, leading to a greater capacity for training on return to SL. The lead-in period to the camp consisted of 10-days of reduced training load prior to travel. Analysis of both the subjective and objective markers of sleep quality took place over two periods: two-weeks of typical training at SL preceding the 10-day lead-in phase in December 2019, and the first two-weeks of the ALT camp in January 2020. A more controlled crossover design was not possible due to logistical restrictions on the swimmers (training and competition) as well as potential carry-over effects from adaptations to training at ALT.

Participants

Fourteen high-performance collegiate swimmers (female n=9, male n=5), enrolled in the University of Edinburgh performance swimming programme, were recruited through convenience sampling for this study. The sample had an age range of 18 to 26 years (mean ± SD; 21.8 ± 2.4 years), were all resident at SL (Edinburgh, altitude range 0-574m, average altitude 130m) and had a mean of 11.4 (± 3.7) years of experience within competitive swimming. The swimmers specialised in sprint and middle-distance races, with primary events across the sample being comprised of a single 50m event, six 100m, five 200m and two 400m events, across the range of strokes. The athletes provided written informed consent before the onset of the study, with ethical approval being granted from the Moray House School of Education and Sport Research Ethics Committee at the University of Edinburgh. Despite the data collection processes being part of the routine monitoring carried out as part of the athlete's training agreements, participation was entirely voluntary and there were no consequences for the athletes who chose not to participate in the study. Withdrawal was possible at any time.

The performance level of the sample was quantified through the Fédération Internationale De Natation (FINA)[20] point scoring system, where a point score was attributed to each swimmer based on their pre-study personal best time in their primary event. Scores could range from 0 to 1000, and were ascribed based on the 2019 world record times in each event, where a world record equals 1000 points.[20] The sample held a mean of 836.0 (± 35.1) points, which falls within level 2 of Ruiz-Navarro and colleagues[21] swimming research performance classification model. This level is based on the B qualifying standards for FINA international events, which corresponds to a range of 800 to 875 FINA points, highlighting the high-performance nature of the sample.

Training

Both the SL and ALT training periods consisted of similar schedules, with training days containing morning (7:00-9:00am) and afternoon (2:00-4:00pm) pool sessions and a land-based conditioning session. The training programme for the first 14-days at altitude is outlined in Table 1. Training load was calculated for all sessions by multiplying the duration (minutes) by the RPE for that session (modified Borg scale from 1-10).[22] This was then totalled to provide a measure of weekly training load. Weekly training volume in metres (m) was also recorded. The swimmers were highly familiar with this process, being required to complete it daily as part of their required duties as performance squad athletes.

*****Please insert Table 1 near here*****

Subjective Sleep Quality Assessment

The athletes provided subjective measures of their sleep quantity and quality through completion of the Athlete Sleep Screening Questionnaire (ASSQ)[23] at the end of both two-week sleep assessment periods. The ASSQ is a 16-item questionnaire that assesses both sleep and circadian aspects related to an athlete's sleep quality, quantity, timing, disturbance, insomnia and disordered breathing. A 'sleep difficulty score' is calculated from the answers, provided on a scale from 0 to 17, which categorises athletes based on the degree to which the reported answers suggest the presence of a clinical sleep problem:

- Scores 0 to 4: no clinical sleep problem.
- Scores 5 to 7: mild clinical sleep problem.
- Scores 8 to 10: moderate clinical sleep problem.
- Scores 11 to 17: severe clinical sleep problem.

The athletes completed the questionnaires in their training environment, in the presence of the primary researcher, being advised that the answers were to best represent the nights of the preceding two-weeks only. Within a sample of 46 Canadian national-team athletes, the ASSQ has been validated to have acceptable vales of internal consistency (Cohen's Kappa = 0.74) and test-retest reliability (ICC = 0.86).[24] When compared to a sleep assessment by a professional sleep medicine physician specialising in the sleep of elite athletes, the ASSQ demonstrated good agreement (Cohen's Kappa = 0.84), with a diagnostic sensitivity of 81%, specificity of 93% and positive and negative predictive values of 87% and 90% respectively.[24] While the athletes had not previously completed the ASSQ, they were highly familiar with recording subjective sleep quantity and quality within daily wellbeing diaries and had previously completed similar sleep questionnaires.

Objective Sleep Quality Assessment

Sleep quality was assessed objectively using MotionWatch 8 wrist-worn actigraphy devices (CamNtech, Cambridgeshire, United Kingdom). As recommended by Sargent, Lastella, Halson & Roach,[25] the watches were worn on the non-dominant limb and set to have a high sensitivity to sleep, with activity recorded in thirty second epochs, as this setting has shown to have the greatest levels of agreement, specificity and sensitivity when compared to the gold-standard measure of sleep quality – polysomnography (PSG) – in a sample of elite athletes. Seven sleep parameters were recorded and reported for each night of both two-week periods, namely: time of sleep onset, time of wake onset, time spent in bed, total sleep time, sleep onset latency, sleep efficiency and sleep fragmentation index. These parameters have been defined previously.[26]. Both time of sleep and wake onset were confirmed by comparison to the data provided in the athlete's daily wellbeing diaries, completed as part of their daily duties as performance squad athletes. Only the athlete's main period of nightly sleep was assessed and compared between the two assessment periods. Daytime naps were not included in the analysis. Fragmentation index was taken as the primary objective measure of sleep quality, consistent with Leeder and colleagues.[26] The MotionWatch 8 actigraphy devices have been validated as an accurate method of assessing the above sleep components when compared to PSG in healthy participants.[27] To the author's knowledge, no validation study has been conducted with a sample of elite athletes for these specific devices. The possibility for a Hawthorne effect having an influence on the data recorded by the actigraphy devices is acknowledged.[25] However, the swimmers of the current study were familiar and comfortable with use of these devices through previous sleep assessments, and so the impact of the watches on the sleep of the athletes should have been minimal.

Wellbeing

Daily subjective scores, on a 1-10 scale (10 being the most positive possible response), were recorded for fatigue, body soreness, health and stress each morning throughout the altitude training camp using the 'Smartabase' electronic application (Fusion Sport, Brisbane, Australia). Additionally, each morning before leaving bed, athletes provided measurements of blood oxygen saturation using a finger pulse oximeter (Nonin Medical Inc, Plymouth, UK). The athletes were familiar and comfortable with providing these wellbeing measures.

Statistical Analysis

Descriptive data are presented as means ± standard deviation (SD). Normality of all data was assessed through use of the Shapiro-Wilks test. Difference in the sample mean of the calculated 'sleep difficulty score' from SL to ALT was assessed using the Wilcoxon Signed-Rank test, due to the non-parametric nature of the questionnaire data. Group means for total weekly training load and training volume were compared between SL and ALT using paired-samples t-tests. Each of the seven objective sleep characteristics were compared between the SL and ALT environments through use of a linear mixed model approach[28], controlling for training load as a fixed-effect covariate. This method allows for the appropriate analysis of repeated-measures data by including the participants as random effects, allowing for within-subject standard deviations[28]. Z-score analysis of each of the seven sleep parameters was also conducted for each athlete, comparing their value for each night at ALT to their own average value for each parameter from the two-week SL sleep assessment period. Associations between a number of the collected variables were assessed through Pearson Product Moment correlations, with effect sizes described as trivial ($r < 0.1$), small ($0.1 \leq r < 0.3$), moderate ($0.3 \leq r < 0.5$) or large ($r \geq 0.5$)[29]. These associations were: individual change in ASSQ score and fragmentation index from SL to ALT; mean values of the wellbeing markers and both objective and subjective sleep quality at ALT; and individual change in training load and both objective and subjective sleep quality from SL to ALT.

All null hypothesis significance testing (NHST) analyses were conducted using IBM SPSS Statistics (Version 25.0, IBM, Chicago, IL, USA), with the significance level set at $p<0.05$. Further, due to Wasserstein & Lazar's[30] recommendation to avoid relying on NHST alone for the statistical analysis of data, Cohen's d effect sizes, with 95% confidence intervals, were ascribed to all comparisons where applicable. The magnitude of these effect sizes are defined as trivial ($d < 0.2$), small ($0.2 \leq d < 0.5$), moderate ($0.5 \leq d < 0.8$) or large ($d \geq 0.8$), with d representing units of standard deviation.[29]

Results

Athlete Sleep Screening Questionnaire

A statistically significant increase ($Z = -2.203$, $p = 0.028$, $d = 0.76$, 95% C [-0.01, 1.52]) was identified in ASSQ 'sleep difficulty scores' from the group mean at SL (4.9 ± 1.7 au) to ALT (6.6 ± 2.3 au), indicating a group trend of decreased subjective sleep quality at ALT (Figure 1). Across the sample, eight athletes were found to have a greater 'sleep difficulty score' at altitude, with five athletes having no change in score, and one athlete found to have an improved quality of subjective sleep at altitude. Figure 1 also demonstrates the increased proportion of swimmers reporting clinical sleep problems at ALT, based on their ASSQ sleep difficulty scores.

*****Please insert Figure 1 near here*****

Wristwatch Actigraphy

The sample mean for each of the seven sleep characteristics, for both the SL and ALT environments, are displayed in Table 2. No statistically significant differences were identified between SL and ALT across the seven characteristics. The difference between the group means for 'time spent in bed' approached statistical significance ($F_{(1, 24.96)} = 3.968$, $p = 0.057$, $d = 0.62$, 95% CI [-0.14, 1.38]), with athletes spending 19 minutes longer in bed on average while at ALT compared to at SL.

*****Please insert Table 2 near here*****

Night-by-night Z-score analysis of fragmentation index, taken as the objective measure of sleep quality from the actigraphy-based assessment of sleep,[26] is presented in Figure 2 for the first two weeks of the ALT camp. Rest/recovery days are highlighted as the latter three coincide with decreases (improvements) in fragmentation index.

*****Please insert Figure 2 near here*****

Association between Change in Objective and Subjective Sleep Quality

A negative, statistically non-significant ($r = -0.481$, $p = 0.082$), association was identified between individual change in ASSQ 'sleep difficulty score' and fragmentation index from SL to ALT, however did display a moderate effect size (Figure 3).

*****Please insert Figure 3 near here*****

Training Load and Volume

Average (±SD) weekly training load increased by 30.2% ($t_{(13)} = -4.202$, $p = 0.001$, $d = 1.54$, 95% CI [0.70, 2.39]) from 3521.8 au (±660.0) during the two-week SL sleep assessment period to 4584.9 au (±1042.6) throughout the first two weeks of the ALT training camp. Mean pool-based weekly training volume significantly increased by 22.8% ($t_{(13)} = 7.268$, $p < 0.01$, $d = 2.53$, 95% CI [1.53, 3.52]) from 33,372m (±2573m) at SL to 40,840m (±3848m) at ALT. Associations between individual changes in training load from SL to ALT and changes in ASSQ 'sleep difficulty score' ($r = 0.329$, $p = 0.126$) and fragmentation index ($r = -0.361$, $p = 0.102$) were not statistically significant, but had 'moderate' effect sizes.

Wellbeing Markers

Pearson Product Moment association values between mean values for each of the wellbeing markers and both mean ASSQ score and fragmentation index at ALT are displayed in Table 3. A statistically significant negative association, with a moderate effect size, was identified between subjective health and ASSQ score at ALT ($r = -0.480$, $p = 0.041$). There were no other statistically significant associations observed.

*****Please insert Table 3 near here*****

Discussion

The present study aimed to provide some of the first empirical data comparing both objective and subjective markers of sleep quality between SL and moderate ALT in high-performance collegiate swimmers. The principal discovery of the study was that despite the athletes reporting a subjective decrease in sleep quality at ALT compared to SL; this was not observed in the objective assessment, demonstrating an inconsistency in the findings between the two assessment methods. However, an interesting discovery was that additional rest and recovery appeared to lead to the improvement of objective measures of sleep quality while at ALT; specifically, a reduction in the degree of sleep fragmentation in the nights following a day-off from training, which was not observed at SL.

Comparison of the ASSQ 'sleep difficulty scores' between the two sleep assessment periods identified a significant increase with a moderate effect size (Figure 1) from SL to ALT, with only a single athlete reporting improved subjective sleep (decrease in 'sleep difficulty score') in hypoxia compared to at SL. Previously, there have been several anecdotal reports of poor and restless sleep while at ALT[9] coming from athletes, coaches and support staff teams.[14] Additionally, the current study identified an increase in the number of athletes recognised to have a moderate or severe clinical sleep problem, as categorised by their 'sleep difficulty score' (Figure 1) from SL to ALT. In accordance, Lastella and colleagues[18] identified that international team sport athletes subjectively rated their sleep as worse than SL at both low and moderate ALTs. However, sleep quality stabilised following five to six days at ALT, suggesting the initial dip in sleep quality may have been the result of travel fatigue, jet lag and acclimatising to a new sleeping environment rather than the hypoxic environment of ALT.[16] It was also found that a statistically significant association existed between mean subjective measures of daily health and ASSQ score at ALT (Table 3), suggesting that athletes who felt poorer subjective health also experienced decreases in subjective sleep quality, and vice-versa. A poor sleep quality can be an indicator of illness in athletes at altitude[9], and so this finding highlights the importance of monitoring subjective sleep values during hypoxic training camps to provide further insights into athlete wellbeing.

It is noted that the findings discussed above may have been biased by a possible expectancy effect, as the athletes had previously completed the ASSQ at SL and may have assumed that sleep should be worse at ALT, therefore reflecting this in their answers to the questionnaire. However, there was a month-long period between the completion of the SL and ALT questionnaires, providing sufficient time to avoid recall having a substantial influence on the answers provided.[31] The suggestion of impaired sleep quality at ALT, and its association with subjective ratings of health, identify a need for the effective monitoring of athlete sleep while completing an ALT training camp, as any possible sleep disruption or illness symptoms may reduce the efficacy of the training intervention.[32]

While completion of the ASSQ provided a general overview of sleep quality across the two sleep assessment periods, greater resolution and a more specific picture of how nightly sleep changed over time was provided by the seven sleep characteristics assessed by the actigraphy devices. In contradiction to the findings of the subjective sleep quality assessment, the objective analysis identified that there was minimal difference in the sleep of the swimmers between SL and ALT. Of the seven sleep components, only a single difference was identified to be approaching statistical significance between the two sleep assessment periods, demonstrating a slightly greater time spent in bed at ALT compared to SL, with a moderate effect size. While the other six sleep components did demonstrate slightly worse sleep quality at ALT, all effect sizes were either small or trivial (Table 2). In contrast, it has recently been shown that total sleep time and light sleep decreased, while deep sleep and respiration rate during sleep increased in senior national-team endurance athletes at 1800m when compared to SL.[19]

Other previous research conducted in this area, which has investigated the sleep of athletes at natural ALT, has focused on high rather than moderate ALTs (>3500m). It was found that exposure to high natural ALT (3600m) in elite youth team sports athletes was found to elicit both acute and chronic sleep disruption.[15] Further, in a companion paper, 50% of the same sample exhibited impaired breathing during sleep, with REM sleep being the worst affected sleep stage at ALT.[16] As stated previously, the ALT at which these studies were conducted is higher than the moderate ALTs of between 1800 and 2500m at which LHTH camps typically take place.[1] It may be that the increased training load typical of LHTH camps at moderate ALTs, and as observed in the present study, elicits a degree of fatigue and tiredness which allows maintenance of sleep quality when compared to SL,[33] whereas at more severe ALTs, the negative impact of hypoxia on sleep quality cannot be offset by increased fatigue and tiredness.

Despite no statistically significant differences being identified in the seven actigraphy sleep characteristics between ALT and SL (Table 2), the objective assessment of sleep quality demonstrated a curious pattern in the night-to-night variation of the fragmentation index of the swimmer's sleep over their first two weeks at ALT (Figure 2). Importantly, fragmentation index, a measure of how restless or peaceful sleep episodes are, was found to substantially improve in the nights following the athlete's rest/recovery days in their training schedule. This pattern was not evident throughout the SL assessment. This appears to suggest that rest and recovery from the intense training period typical of an ALT training camp is necessary to allow for a higher quality of sleep overnight. This, in turn, will allow improved athlete recovery and performance in training.[13] In accordance, Knufinke and colleagues[34] discovered that in 98 national and international Dutch athletes, there was an elevated occurrence of wake after sleep onset identified by wrist-worn actigraphy devices when there was a perception of a higher than usual training load. In addition, Hausswirth and colleagues[35] have previously identified, during periods of elevated training load, that athletes experience an increase in sleep disturbance and decreased sleep efficiency. Taken together with the findings of the present study, the risk of disturbed sleep and the associated negative implications for recovery, wellbeing and performance in training appears to be elevated when training volume and intensity are increased, such as during an ALT camp. However, well-planned rest and recovery days enable athletes to cope better.

Implications and Practical Recommendations

The comparison of sleep quality between SL and moderate ALT conducted in the current study identified a discrepancy between objective and subjective measures in high-performance collegiate swimmers. Although the athletes reported a significant decrease in their subjective quality of sleep at ALT, as demonstrated by the greater mean 'sleep difficulty score' when compared to SL (Figure 1), minimal difference was observed in the objective analysis of sleep quality between the two environments. Additionally, the association between the change in the objective and subjective sleep variables was not statistically significant (Figure 3). Despite this, the suggestion of disturbed sleep while at ALT should be taken seriously, with possible negative implications for wellbeing, recovery and performance in training.[8] It is therefore recommended that individual sleep monitoring be conducted by practitioners at ALT, in order to identify those who suffer from sleep disruption and allow interventions to be put in place to optimise conditions for all athletes.[15] Furthermore, both objective and subjective measures of sleep quality assessment should be used, to increase the probability of obtaining an accurate insight into the athlete's actual quality of sleep, and identify any illness driven decrease in sleep quality. In addition, it was identified that following rest/recovery days from training, the sleep disruption of the swimmers was substantially decreased (Figure 2). This highlights the importance of ensuring sufficient rest and recovery is planned into the structure of an ALT training camp, allowing for an increase in the quality of sleep that athletes can achieve, subsequently leading to improvements in the capacity to train and elicit the desired adaptations from the ALT intervention.[5]

Strengths, Limitations and Future Research

The principal strength of this study lies in the inclusion of both subjective and objective assessments of sleep quality, allowing for comparison between the two. As identified, the inconsistency between the findings of the two assessment methods suggests a potential for the reporting of inaccurate results. Secondly, the ASSQ is a questionnaire specifically designed and validated for use with samples of athletes, taking into account the difference in sleep habits when compared to the general population[23]. Future research could look to compare the gold-standard measure of sleep assessment – PSG – between SL and ALT, should facilities allow.

The primary limitation of the current study lies in the fact that during the SL two-week sleep assessment period, the athletes were sleeping in their familiar home environment, whereas at ALT it was an unfamiliar sleeping environment with athletes sharing rooms with teammates. This may have contributed to the reduction in subjective sleep quality reported.[13] Future research could look to investigate the difference between the sleep of athletes in training camp environments both at SL and ALT. This should also allow for a greater similarity in the training load and volume between the two assessment periods, as the significantly greater training load at ALT in this study may have confounded the sleep assessment results. However, it was identified that the association between the change in training load between SL and ALT and the change in ASSQ score and fragmentation index were both statistically non-significant, bringing into question the effect the increase in training load had on the sleep of the high-performance swimmers. A further recommendation for future research is weekly completion of the ASSQ, in order to provide greater insight into the change of subjective sleep quality throughout an altitude sojourn, potentially identifying the effects of travel fatigue and jet lag early in the camp. Finally, the athletes within the sample held a range of prior experience with ALT training, meaning some might have been more accustomed to sleeping in the hypoxic environment than others.[13] Future studies could look to investigate if there is a difference in the degree of sleep disturbance at ALT between athletes accustomed to attending ALT camps and those experiencing it for the first time.

Conclusion

This study has identified an inconsistency in the subjective and objective comparison of sleep quality between SL and a moderate natural ALT environment in high-performance collegiate swimmers, with the athletes perceiving a greater increase in sleep disruption than was found through objective assessment. Additionally, night-by-night sleep analysis at ALT identified a substantial improvement in sleep disruption following rest/recovery days from the athletes' training routine. The suggestion of disturbed and impaired sleep outlines the importance of accurate sleep quality monitoring while at ALT, allowing conditions to be optimised for all athletes in order to maximise the chances of a successful training intervention. Further, the need for sufficient periodised time for rest and recovery throughout the meso-cycle of an ALT training camp has been highlighted, allowing athletes to obtain a greater quality of sleep overnight. Coaches and support staff should pay particular attention to the sleep quality of their athletes, and the methods used to assess sleep, throughout a period of terrestrial moderate ALT training.

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Declaration of Interest Statement

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Tables

Table 1.

	Day 1	**Day 2**	**Day 3**	**Day 4**	**Day 5**	**Day 6**	**Day 7**
Session 1 07:00 – 09:00	Travel to altitude.	Swim	REST AM	Swim	REST DAY	Swim	Swim
Session 2 14:00 – 16:00		Swim	Swim	Swim		Swim	Swim
Session 3 16:30 – 17:30		Land-based S&C	Land-based S&C	Land-based S&C		Land-based S&C	Land-based S&C
	Day 8	**Day 9**	**Day 10**	**Day 11**	**Day 12**	**Day 13**	**Day 14**
Session 1 07:00 – 09:00	Swim	REST DAY	Swim	Swim	Swim	REST DAY	Swim
Session 2 14:00 – 16:00	Swim		Swim	Swim	Swim		Swim
Session 3 16:30 – 17:30	Land-based S&C		Land-based S&C	Land-based S&C	Land-based S&C		Land-based S&C

Table 2.

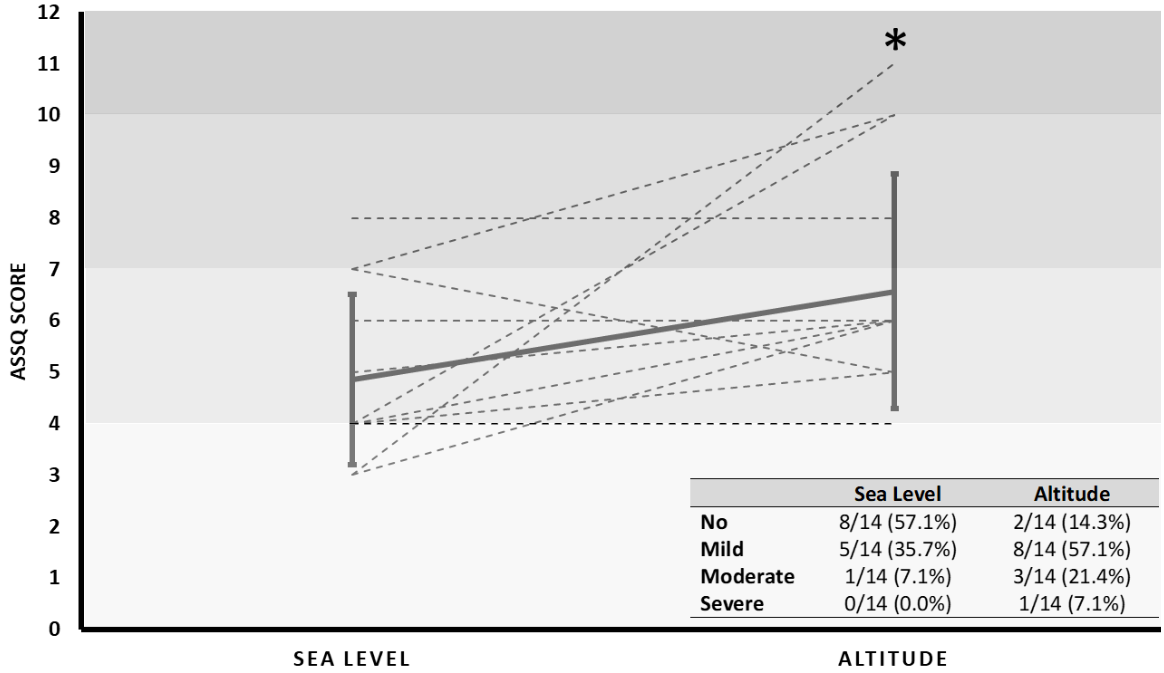
	Sea Level (Home) Mean (SD)	**Altitude (Training Camp)** Mean (SD)	**Effect Size** *d* [95% CI]
Sleep Time	23:07 (00:36)	22:58 (00:16)	-0.20 [-0.94, 0.54]
Wake Time	07:08 (00:21)	07:11 (00:14)	0.08 [-0.67, 0.82]
Time in Bed	08:25 (00:31)	08:44 (00:30)	0.62 [-0.14, 1.38]
Sleep Duration	06:49 (00:27)	06:56 (00:20)	0.23 [-0.51, 0.98]
Sleep Latency	00:22 (00:18)	00:28 (00:17)	0.45 [-0.30, 1.20]
Sleep Efficiency (%)	81.4 (6.0)	79.7 (5.1)	-0.29 [-1.04, 0.45]
Fragmentation Index	28.9 (7.1)	31.0 (6.1)	0.45 [-0.30, 1.20]

Table 3.

	ASSQ Score			Fragmentation Index		
	r	*p*	ES	r	*p*	ES
Fatigue	0.18	0.260	Small	0.07	0.411	Trivial
Soreness	0.07	0.410	Trivial	-0.05	0.433	Trivial
Health	-0.48	0.041*	Moderate	-0.03	0.454	Trivial
Stress	-0.36	0.106	Moderate	0.05	0.436	Trivial
O_2 Sat.	-0.21	0.241	Small	-0.12	0.346	Small

Figures

Figure 1.



	Sea Level	Altitude
No	8/14 (57.1%)	2/14 (14.3%)
Mild	5/14 (35.7%)	8/14 (57.1%)
Moderate	1/14 (7.1%)	3/14 (21.4%)
Severe	0/14 (0.0%)	1/14 (7.1%)

Figure 2.

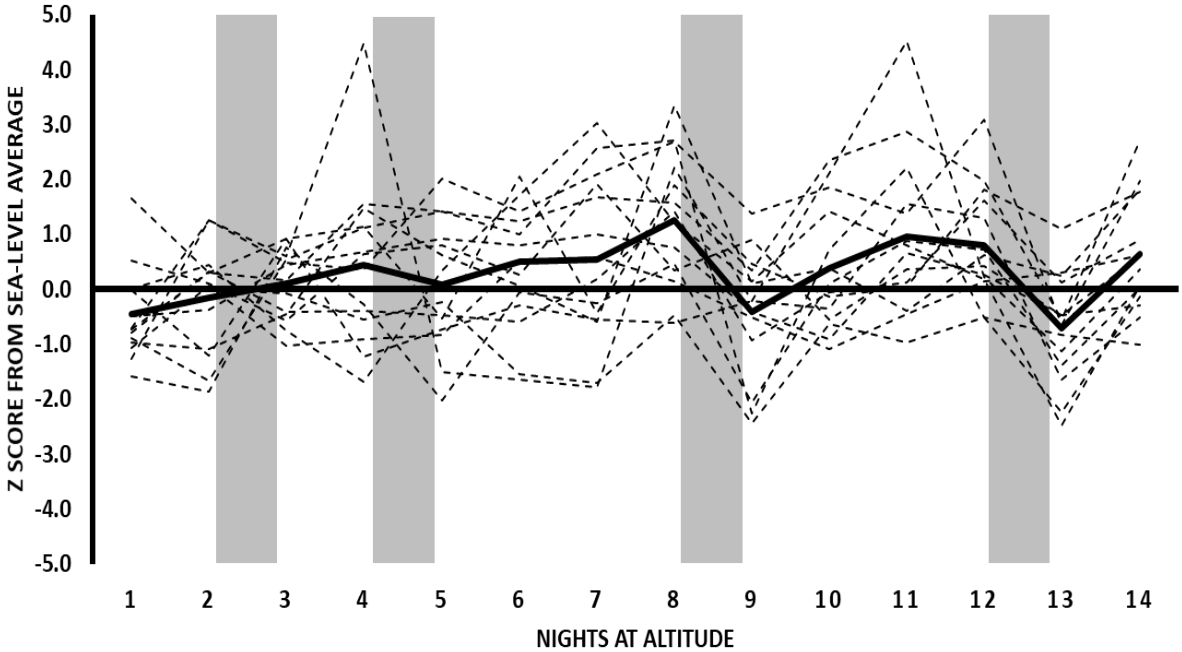


Figure 3.

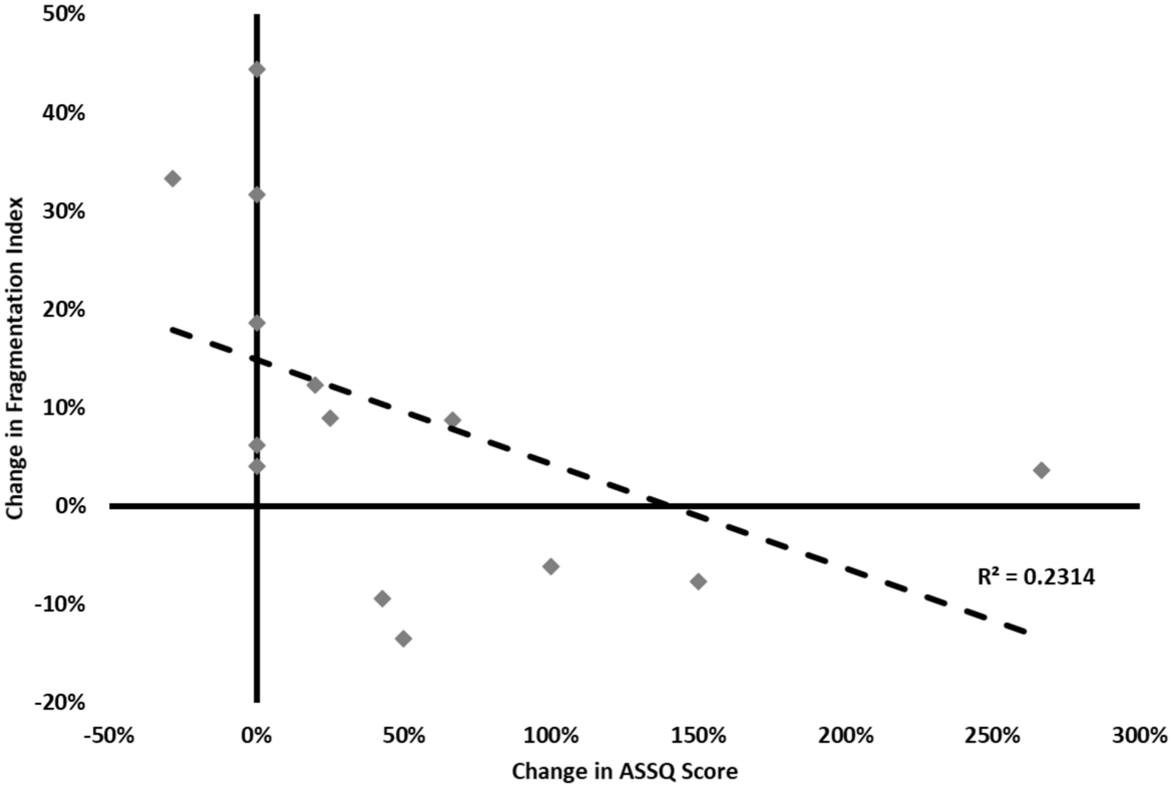

50%
40%
30%
20%
10%
0%
-10%
-20%
Change in Fragmentation Index
R² = 0.2314
-50%
0%
50%
100%
150%
200%
250%
300%
Change in ASSQ Score

Table & Figure Captions

Table 1. Training schedule for the first 14-days of the altitude training camp. S&C = strength and conditioning.

Table 2. Comparison of objective sleep characteristics measured with wrist actigraphy devices at SL and at ALT. Cohen's d effect sizes, with 95% confidence intervals, are displayed for each comparison from SL to ALT.

Table 3. Pearson Product Moment association values between mean daily wellbeing values, ASSQ 'sleep difficulty score' and Fragmentation Index at ALT. r = Pearson correlation coefficient. *P* = Probability value. ES = Cohen's correlation coefficient effect size.

Figure 1. Athlete Sleep Screening Questionnaire (ASSQ) 'sleep difficulty score' for each athlete for two-week periods at home (SL) and during the training camp (ALT). Group mean (±SD) displayed in **bold.** Significant difference in the group mean from SL identified with an asterisk. Number (percentage) of athletes placed in each category of degree of clinical sleep problem based on ASSQ 'sleep difficulty score' is displayed in Table inset. These categories are also displayed on the figure, with darker shading representing greater degree of clinical sleep problem.

Figure 2. Z-score of 'Fragmentation Index' for each of the first 14-nights of the ALT training camp for each athlete (calculated as number of standard deviations from each athlete's own average fragmentation index from the initial two-week sleep assessment period at SL). Group mean Z-score for each night displayed in **bold** (calculated as number of standard deviations the group mean of fragmentation index for each night at altitude was from mean fragmentation index of all athletes across the entire initial two-week sleep assessment period at SL). Note a positive Z-score represents an increase in 'Fragmentation Index' and so a decrease in sleep quality. X-axis represents nights spent at altitude. Rest/recovery days (between nightly periods of sleep) are highlighted in grey. *Day 3 was AM rest only – athletes trained PM (see Table 1).

Figure 3. Scatter plot displaying association between individual percentage change in ASSQ 'sleep difficulty score' and fragmentation index between SL and ALT, with linear trendline and R^2 value displayed. Note, an increase in fragmentation index and ASSQ score both represent a decrease in sleep quality.