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Sleep quality and cardiorespiratory endurance in adolescent competitive swimmers

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ABSTRACT

Being able to last through a race is largely determined through training and endurance ability in swimming. Sleep is also a way to improve recovery and thus is regarded as a way to modify recovery and support adaptation to cardiorespiratory activities of young athletes by experts. Not many studies have looked at this relationship between sleep quality and sport performance in adolescent swimmers from clubs compared to that of elite swimmers or college players. Through this study, we wanted to establish whether or not sleep and cardio capacity can go hand in hand with our teenage swimmers from Ladies Swimming Club. We applied a numerical correlational model to the situation and a complete sampling of the population as only 10 swimmers were on the register (ages 13 to 17, mean age was 14.8 and SD was ±1.48). The instrument employed to evaluate sleep quality of athletes during the study was the Pittsburgh Sleepiness Scale (PSQI) and VO_2max was calculated from the Multistage Fitness Test (Bleep Test) using Ramsbottom formula. Analysis of the data included the Shapiro-Wilk test of normality and then the Pearson correlation if there was no departure from normal distribution. Findings: The PSQI range was 2 to 13 (M = 6.30, SD = 3.09); 60% of swimmers were considered as having a good sleeping habit while the remaining 40% slept not too well. The estimated VO_2max values varied from 33.32 to 53.50 ml/kg/min (M = 44.54; SD = 7.51). Both PSQI and VO_2max measures were within the normal distribution (PSQI: W = 0.909, p = 0.271; VO_2max: W = 0.876, p = 0.118). The result shows that there was a strong and negative relationship between PSQI and VO_2max with a significant statistical level (r = -0.910, p = 0.00025), meaning that sleep quality was the major reason behind such variations in endurance (R^2 = 0.8288). Our findings demonstrated that sleep quality is linked with cardiorespiratory endurance. Lower quality sleep was associated with lower endurance. Areas of use: It would be beneficial for coaches and other professionals involved in athletes' development or training to include the monitoring of athletes' night time sleep and provide education on sleeping habits into their daily routines, since they are responsible for a large part of the training plan and hence of the athletes' period and recovery as well.

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Introduction

Elite sport performance can be traced back to the combination of systematic, data-driven preparation involving physical fitness, skill mastery, strategic insight, and mental resilience, as Parry (2023) stated. Argantos

(2024) points out that among the different physical attributes that influence performance, endurance the ability to prolong physical exertion, resist the effects of fatigue, and preserve energy reserves for future tasks forms the backbone of success in sports that rely heavily on endurance.

Swimming is undoubtedly the most demanding on a physiological level of these sports. It involves almost simultaneous use of almost all major muscles, along with breathing coordination, technique, and cardiorespiratory capacity to overcome water resistance (Afrizal et al., 2025; Denay, 2022). Therefore, a successful outcome in competitive swimming relies on a combination of different factors: physical fitness, perfecting the technique, sufficient training, nutrition, and mental state (Fone & Tillaar, 2022). In the framework of many factors influencing one single result, recovery, and more specifically sleep, has become the subject of an increasing body of scientific literature pointing out that this is one of those factors that can be modified when it comes to training adaptation and endurance capacity (Lundstrom et al., 2025).

During sleep, the body goes through essential repair work, restoring energy, hormonal regulation, and consolidates functions of the brain and metabolism (Lendner et al., 2023). A wide range of literature, available nowadays, establishes relationship between short or/and low quality of restorative sleep and reduced sporting results. In their studies, authors who use the technique of systematic review have found out a decrease of explosive power, sprint speed, etc. under a condition of sleep restriction, whereas continuous sleep deprivation triggers increased physiological stress such as high heart rate, lung capacity, and lactate accumulation that lead to sooner fatigue and a smaller VO_2max (Mądry, 2025). Papers that present narrative and mechanistic reviews have also identified disturbed growth-hormone production, imbalanced autonomic nervous system functioning, and uncontrolled ghrelin/leptin hormones as underlying mechanisms that poor sleep can use to undermine the effectiveness of muscular and cardiorespiratory recovery from training (Marques et al., 2025). This is in line with earlier systematic and expert-consensus research suggesting that sleep depravation leads to poorer exercise performance both at the submaximum level and the peak level, that is, sleep deprivation is currently understood as a risk factor that is changeable, requiring regular monitoring and intervention, and affecting a broader segment of sports individuals (Fullagar et al., 2015; Walsh et al., 2021).

A pattern is reinforced by evidence related to swimming. In a group of top collegiate swimmers, both sleep duration and the percentage of slow-wave sleep were independent factors predicting performance in a 200 yard time trial, with higher sleep quantity and quality being associated with faster finishing times (Lundstrom et al., 2025). PSQI-assessed sleep quality among adolescent competitive swimmers was independently linked to the swimming distance classification and functional respiratory indices that showed sleep disruptions can be measured, hence performance-related even at non-elite, developmental levels of competition (Stavrou et al., 2024). Similar relationships between sleep quality, cardiorespiratory fitness indices, and shuttle-run based endurance performance have been reported in youth soccer players as well, thus, it appears that the sleep-endurance relationship is applicable to all sports where endurance is essential, and where sports are performed intermittently or cycling (Cabarkapa et al., 2024). Competition swimming has already been shown by previous field studies as one of the sports where athletes suffer considerable sleep deprivation because the early-morning training programme severely limits the total amount of sleep (Sargent et al., 2014). Reduction of attentional control and perceptual ability due to sleep deprivation have also been reported specifically in young athlete population thus, younger competitors are at higher risk of poor sleep performance-related consequences than older ones (Stavrou et al., 2021). Cluster analysis of the sleep profiles of endurance athletes indicates that a better sleep quality is generally associated with more favorable recovery and performance outcomes across various endurance disciplines (Matos et al., 2025).

Most of the studies done to this day have focused on elite, collegiate, or adult athletes using objective sleep measures such as polysomnography or actigraphy under the guidance of sport science professionals in highly resourced environments. Only in very few studies the sleep, endurance interaction has been studied among adolescent athletes in community or youth swimming programmes in Southeast Asia where sport-related demands regularly clash with schoolwork and where sleep and fitness screening tools (PSQI and Multistage Fitness Test) are considered more convenient field-level instruments than lab-based alternatives.

The gap is very much directly related to the Women Swimming Club, a swimsport activity run by a local community in Indonesia, that keeps a strict training schedule for their young athletes. Some early observations combined with the interview with coaches suggested that a quite number of athletes showed early signs of tiredness, the inability of maintaining a fast pool speed during a whole training time, lack of concentration, and visible signs of a tired person during their sessions--coach team members had anecdotally referred these patterns of sleep habits to school workload and night-time device use resulting in irregular sleep habits. For some other athletes, they mentioned that their sleep was on an average of seven hours or less per night and this was a point of concern that sleep problems could be a limiting factor in the physical stamina needed for both training and competing. However, nobody had empirically proven such connection within the group in question. This casual evidence matches with the fact that the use of smartphones and other screens after dark by adolescents has been identified in multiple cases as factors that cause later sleep initiation and worse sleep quality from the perspective of the individual, particularly those based in the area of the PSQI (Naing et al., 2024; Tkaczyk et al., 2023).

This paper builds upon the body of literature mentioned previously and focuses on filling the research gaps in five interconnected dimensions.

It seems that despite the well-established relationship between sleep performance and performance in adult and collegiate competitive swimmers (Lundstrom et al., 2025), quantitative data on how sleep quality, as assessed by the PSQI, impacts aerobic performance, measured as VO_2max on the field remains very limited in adolescent, club-level swimmers.

A number of studies linking sleep and swim performances mostly depend on lab equipment (e.g., actigraphy, polysomnography) that is too complicated for regular use in community sports; therefore, our work shows how affordable and portable devices (PSQI and Bleep Test) can be used to track sleep-swim relationship in limited club conditions without sophisticated equipment.

Prior swimming-specific studies have concentrated on elite collegiate or national-championship-level cohorts (Lundstrom et al., 2025; Stavrou et al., 2024); adolescent athletes training within grassroots, club-based programmes in Indonesia constitute a distinct and understudied population with different training loads, resources, and lifestyle demands. At present, swimming club coaches and administrators can not find enough locally produced research or evidence to show sleep education and monitoring should be part of training programs. As such, they can't translate the recovery-science discoveries from an international perspective into grassroots coaching practice very far.

Although the physiological mechanisms that connect sleep and endurance capacity (e.g., release of growth hormones, autonomic adjustment of the organism, synthesis of muscle glycogen) are well explained in general exercise physiology (Marques et al., 2025), the real manifestation of these mechanisms, that is, the extent and direction of thesleep VO_2max association, has not yet been investigated in these athletes resulting in a gap between a theory that seems plausible and the local empirical confirmation of it. The authors of the study, through their research, have demonstrated for the first time in a swim club of adolescents, the relationship between sleep and stamina at the field level. The research is adding an adolescent swim context to the sleep and performance area of theory, apart from elite and college ones. Combining the Sleep Quality Questionnaire with the Multistage Fitness Test (Bleep Test) using the Ramsbottom VO_2max formula provides an affordable, field-deployable method that community swimming clubs without laboratory facilities can replicate practically.

Results serve up local, real-life, and implementable evidence to coaches at the Women Swimming Club and similar programmes to support the proposal of introducing sleep-hygiene teaching as part of periodised training plans; By sharing data from the sleep and physical conditioning field, the report opens up a new avenue, not only for those working in community sports but also for researchers in various parts of the world. Whereas prior studies have focused on elite, collegiate, or adult swimmers using laboratory-based sleep measures, this research uniquely investigates the sleep-endurance relationship among adolescent, club-level swimmers using field-deployable instruments. This study aims to measure the strength, direction, and statistical significance of the association between PSQI-assessed sleep quality and VO2max-estimated cardiorespiratory endurance among adolescent athletes of the Women Swimming Club. In line with these objectives, this study investigated sleep quality of women swimming club athletes, their level of cardiovascular fitness, and also explored strength, direction, and statistical significance of the relationship between these two variables.

H_0: Women Swimming Club athletes have no significant connection between their sleep quality and cardiorespiratory endurance. H_1: Women Swimming Club athletes do have a significant correlation between sleep quality and cardiorespiratory endurance.

Method

The current research was based upon a quantitative, cross-sectional, correlational descriptive study design. This method aims at portraying two research variables and measuring the strength of their relationship through quantification, adhering to the suggestions given in the literature for descriptive correlational research (Von Elm et al. 2007; STROBE reporting guideline).

The study was conducted at the swimming pool of Kolam Renang Teratai, which is part of the H. Agus Salim Sports Complex, after finishing the final research proposal seminar. Data collection was scheduled on 12th July, 2026. The accessible population was women swim athletes only who had been signed up to the Women's Swimming Club. Because there were not so many active members at the time, the researchers used total sampling (census) method, and there were 10 subjects whose ages ranged from 13 to 17 years (M = 14.8, SD = 1.48) who were finally chosen for analysis. In total, all of the questionnaires (instruments) used have been returned by the subjects with a rate of 100% and they all completed the sleep quality questionnaire as well as the endurance test. No a priori power analysis was conducted to justify this sample size for correlational testing; because the club had only 10 registered athletes at the time of data collection, a census (total sampling) approach was adopted rather than a probability sample, and this constraint is acknowledged as a limitation affecting the generalizability of the findings.

Sleep quality (independent variable, X): operationally defined as an athlete's self-reported satisfaction with, and physiological experience of, sleep over the preceding month, encompassing subjective sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbances, use of sleep medication, and daytime dysfunction, measured via the PSQI. Lower total PSQI scores indicate better sleep quality. Cardiorespiratory endurance (dependent variable, Y): operationally defined as an athlete's capacity to sustain progressively intense physical activity without excessive fatigue, estimated as VO_2max (ml/kg/min) via the Multistage Fitness Test. Higher VO_2max values indicate better cardiorespiratory endurance.

Pittsburgh Sleep Quality Index (PSQI) The PSQI measures seven distinct areas, each of which will give a score from 0 to 3, and finally, these will give the total PSQI score (from 0 to 21) that indicates that the person who sleeps less or has more difficulty with sleep has a better PSQI score. It has been widely known that in standard scoring methods for such questionnaires, if the total PSQI score is 5 or less it is considered that the person sleeps well and above 5 it means the person is suffering from insomnia. This sleep quality instrument has been shown in studies with comparable populations that it has very high and adequate content and internal validity respectively (validity coefficient=0.90 and Cronbach's α=0.83) (Tang et al., 2022; Utomo et al., 2025). Meanwhile, researchers in sports science literature have pointed out that the PSQI was initially created and validated based on clinical populations that were not athletes, so structural validity, factor structure and the best period of recall are still under methodological discussion in athletic samples; therefore the use of global scores should be accompanied by the interpretation of the patterns at the individual factor level instead of solely relying on them (Tan et al., 2024). Reliability and validity coefficients specific to Indonesian adolescent athletes were not available for this study; the psychometric figures reported above derive from other athlete populations, and this absence of locally validated reliability data is acknowledged as a limitation of the present study.

Multi-Stage Running Test (Bleep Test) Pulmonary capacity was evaluated by performing the Shuttle Run Multistage Fitness test at the distance of 20 meters which required players to run to and fro at a tempo matched with the audio cues increasing in speed gradually until the player could no longer continue, or failed to reach the line on two consecutive occasions within the specified time. The last level and the number of shuttles successfully completed were registered and used along with the Ramsbottom prediction equation to estimate theVO_2max: $VO_2max = 3.46 \times [L + S(L \times 0.4325 +7.0048)] +12.2$. Predicted VO_2max levels were then assigned to Heywar's (1998) benchmark categories: Poor if <35, below average 35.0, 38.3, Average 38.4, 45.1, Good 45.2, 55 and Excellent >55. The Ramsbottom equation had been later on re-validated against, laboratory-measured standard, criterion VO_2max in various athletic populations and has mostly turned out a field-based valid predictor, which gave confidence to the use of this equipment in this community club setting where treadmill or gas exchange tests were not available according to Magee et al. (2021).

The study was conducted in a manner that aligned with institutional and club policies. Club coaching staff were coordinated and institutional research permission was granted before the work could begin. Each athlete received a PSQI questionnaire individually; the researcher would stay with the athlete throughout and where necessary would be able to explain what the wording of items was about, and all of this would relate sleep patterns of the athlete over the preceding month. Bleep Test, on the other hand, was run at the club premises according to standard protocol (a flat, non-slip 20 x 10 m track, audio pacing, trained timekeepers and scorers were there). Weather made the data collection hard (rain led to protocol change) and there were no enough standard MFT machines on the market that were the ones used. So, it came to the researcher to get the needed equipment from local suppliers; the constraints were both handled in such a way that the standardized test protocol remained intact.

Descriptive statistics (mean, standard deviation, minimum, maximum) were calculated for each of the two variables. Distributional normality was examined through a Shapiro-Wilk test, which is the right choice with a small sample size like ours (n=10); a significance level above 0.05 meant, in our interpretation, was a good representation for a normal distribution. Being that both variables satisfied the normality condition, we decided to assess the relation between sleep quality (via PSQI score) and cardiorespiratory endurance (VO_2max) with Pearson's product-moment correlation. We determined the coefficient of determination ($R^2 = r^2 \times 100\%$) to see just how much the variance between sleep quality and sleep quality was attributable to one another. We considered the size of the correlation coefficient in light of Sugiyono (2023) recommendation: 0.00-0.199 (very low), 0.20-0.399 (low), 0.40-0.599 (moderate), 0.60-0.799 (strong), 0.80-1.000 (very strong). We had to reject our null hypothesis at p=0.05.

The permission for the research was secured with the facility management and club coaches before the beginning of data collection. The participation was on a voluntary basis and the athletes along with their guardians (when appropriate) became fully aware of the aim and methods of the research after being provided with the necessary information by those responsible with organizing the study. Also, each data handler and the person responsible for compiling of the final report were made aware of the importance of maintaining the anonymity of the participants.

Results and Discussions

The research sample was the full 10 players of the local Women's Swimming Club, so all questionnaires could be used for the study with no data lost. Participants' ages varied from 13 to 17 years (M = 14.8, SD = 1.44), which was a group rather homogenous by age. Swimming developmental paths divide athletes by age, the athletes' distribution was evenly spread across the two age groups; also it turned out that all athletes were females (n = 10, 100%), consistent with the Women's Swimming Club membership, see Table 1.

Table 1 <Participant Characteristics by Age Group (N = 10)>

Age Group	Age Range (years)	n	%
KU I	15–17	5	50
KU II	11–14	5	50
Total	13–17	10	100

The global PSQI scores varied between 2 to 13 (M = 6.30, SD = 3.09). On a per-component analysis (Table 2), sleep latency (M = 1.50) and daytime dysfunction (M = 1.30) were found to be the two main aspects of the PSQI total score; in contrast, sleep efficiency (M = 0.10) and use of sleep medication (M = 0.20) were the least disturbing domains. Table 3 presents the distribution of participants who had been classified into good/poor sleep-quality based on the standard PSQI criteria.

Table 2 <Descriptive Statistics of PSQI Components (N = 10)>

PSQI Component	M	SD	Min	Max
1. Subjective sleep quality	1.20	0.79	0	2
2. Sleep latency	1.50	0.97	0	3
3. Sleep duration	0.90	0.88	0	3
4. Habitual sleep efficiency	0.10	0.32	0	1
5. Sleep disturbances	1.10	0.32	1	2
6. Use of sleep medication	0.20	0.42	0	1
7. Daytime dysfunction	1.30	0.82	0	3
Global PSQI score	6.30	3.09	2	13

Source: Primary data (2026).

Table 3 <Distribution of Sleep Quality Categories (N = 10)>

Category	Criterion	n	%
Good	PSQI ≤ 5	6	60
Poor	PSQI > 5	4	40
Total	—	10	100

Source: Primary data (2026).

Estimated VO_2max ranged from 33.32 to 53.50 mlkg/min (M = 44.54, sd = 7.51). This meant the endurance level was on average in the "good" normative band but with a large variability inter-individually. Please consult Table 4 for the full picture. We can see the athletes' share across the endurance levels in normative way by viewing Table 5.

Table 4 <Descriptive Statistics of VO_2max (N = 10)>

Statistic	Value
Mean	44.54 ml/kg/min
SD	7.51 ml/kg/min
Minimum	33.32 ml/kg/min
Maximum	53.50 ml/kg/min

Source: Primary data (2026).

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Table 5 <Distribution of Cardiorespiratory Endurance Categories (N = 10)>

Category	**n**	**%**
Poor	2	20
Average	2	20
Good	4	40
Excellent	2	20
Total	10	100

Source: Primary data (2026).

By Shapiro, Wilk tests, it is evident that both variables have a normal distribution ($p > 0.05$ for both variables), hence justifying the use of the Pearson product-moment correlation method for our test of the hypothesis (Table 6).

Table 6 <Shapiro–Wilk Normality Test Results>

Variable	**W**	**Sig. (p)**	**Interpretation**
PSQI score (X)	0.909	0.271	Normal ($p > .05$)
VO_2max (Y)	0.876	0.118	Normal ($p > .05$)

Source: Primary data (2026).

Pearson product-moment correlation showed that PSQI score and VO_2max have a significant negative large association. $r(8) = -0.910$, $p = 0.00025$. Using the interpretation framework of Sugiyono (2023), it's evident that r (0.910) in absolute term belongs to the 0.80, 1.000 category, indicating the very highest level of a relationship. The coefficient of determination revealed that sleep quality accounted for 82.88% of the variance in cardiorespiratory endurance ($R^2 = 0.8288$), while the remaining 17.12% is due to factors outside of the current study as displayed in Table 7.

Table 7 <Summary of Pearson Correlation and Hypothesis Test Results>

n	**r**	**R^2 (%)**	**p-value**	**α**	**Decision**
10	−0.910	82.88	0.00025	0.05	H_0 rejected; H_1 accepted

Since p (0.24) is less than α (0.05), the null hypothesis has been rejected while the alternative hypothesis is accepted. To put it another way, Women Swimming Club athletes have shown a relationship between sleep quality and cardiorespiratory endurance that is highly statistically significant and at the same time negative and very strong. Sleep quality was poorer for athletes who, in general, demonstrated lower VO_2max. On the other hand, athletes whose sleep quality was relatively better (i.e., lower PSQI scores) showed higher VO_2max.

The analysis of this investigation has revealed, with a high correlation strength and a significant level of evidence, that there is a considerable inverse and statistically significant relationship between sleep hygiene and cardiorespiratory endurance among the members of the Women'Swimming Club who are also adolescents. The sleep quality, a key variable in this relationship, was capable of accounting for approximately 82.88% of the variation observed in VO2max level (r =, 0910, p=0.00025). The outcome of this survey has effectively put to an end the speculation or the doubts that had already been made before in the context of sleep quality and physical conditioning of the swimmers, and it further supports the initial suspicion of coaches and researchers about a subset of athletes whose behavior patterns indicated very early onset of tiredness, decrease of mental focus, and the sign of being very sleepy which are all symptoms reported in connection with under seven hours of nightly sleep.

The negative direction of the relationship fits with the wider sport and science literature regarding sleep and endurance. In college-level swimmers, longer sleep as well as a higher proportion of slow-wave-sleep predicted better performance in a time-trial, highlighting the fact that sleep is, in fact, an assessable factor determining one's endurance capacity in swimming, not just a background condition (Lundstrom et al., 2025). Likewise, sleep quality assessed by the PSQI was a differentiator of functional as well as training-distance categories in adolescent competitive swimmers, suggesting that by taking identical measurements on the same field instrumentation, the sleep, performance pattern observed in professional athletes may be also seen in younger and less elite people (Stavrou et al., 2024). The level of correlation observed in the present experiment is far higher than what is normally reported in these groups, possibly due to the small and uniform group of people tested here as opposed to a completely different underlying mechanism. The systematic and consensus-level reviews, in general, state that the slightest loss or change of sleep quantity or sleep quality is still linked to a decline in exercise capacity, be it submaximal or maximal, in various sports and age groups, which means that the above result is not an isolated phenomenon or just characteristic of a particular population (Fullagar et al., 2015; Walsh et al., 2021).

On top of that, this work agrees with Indonesian studies done before that also associate sleep quality with physical fitness and endurance across different populations and sports. Football players for example, have a very strong association between sleep quality and anaerobic performance (Jati et al., 2023), in a study conducted by the researchers on school children also showed that those who slept better are more fit, both physically (Gunarsa et al., 2022) and in terms of sleep time plus physical activity explaining the majority of differences in fitness outcomes (Utomo et al., 2025). Overall, the research done so far along with our result show that this sleep-endurance relation is not just limited to a particular age group, culture or even sport, thereby establishing sleep quality as an important determinant of physical work capacity.

A number of different physiological processes can be expected to form the basis of this association. Slow-wave sleep is the main period during which pulsatile growth-hormone (GH) is released, supporting muscle protein synthesis, tissue repair, etc. Short- or broken-up sleep is a limitation of that period and may result in impaired repair processes required for training adaptations to continue (Marques et al., 2025). On top of this, low or poor sleeping has been reported to lead to higher activity of the sympathetic nervous system, ghrelin and leptin regulation disruption, and higher exertion levels during exercise, manifested by, e.g., heart rate, respiration, and lactate buildup, all these combined lead to faster fatigue and reduced VO_2max performance in maximal or close-to-maximal exercises (Mądry, 2025). Sleep-extension research with collegiate athletes has corroborated at the intervention level the mechanistic explanations for these sleep-deprivation-induced changes: sleep extension leads to better short-sprint and reaction-time performance, thus providing another argument that habitual sleep disturbance and aerobic capacity are negatively related (Mah et al., 2011). These mechanisms make it possible to explain in physiological terms why athletes with higher (and thereby worse) PSQI scores in the current sample were associated with lower estimated VO_2max.

On a practical level, the exceptionally strong correlation seen here suggests that the Women Swimming Club should be open to the idea of employing a coach to work on improving sleep habits as part of their physical conditioning program. A combination of measures like formal lessons on sleep-hygiene, protecting sleep hours with the modification of training times and setting restrictions on evening screens exposure may well work for the community level as it has done in elite swimming. In fact, insufficient sleep is considered one of the significant modifiable factors affecting training and competition achievements that elite swimmers are struggling with (Lundstrom et al., 2025). Furthermore, research on elite athletes clearly reveals that among the various methods sleep education and monitoring programmes are those that produce consistent gains in sleep indices of athletes much more than single-component or short interventions and hence they can also be adjusted to meet the limited resources of the community swimming club (Bonnar et al., 2018; O'Donnell et al., 2018). On top of this it may be worthwhile to mention that introducing simple, field-deployable forms of sleep monitoring, like the one in our study, as routine coaching tool rather than keeping it for crisis periods only may well be regarded as a recommended practice from sleep-science to athlete lifestyle change. That has already been proposed as a desirable practice (Halson, 2019).

Coaches are advised to regard incorporating sleep monitoring and educating on sleep as part of periodized training planning, equally with physical conditioning and technical skills training. Athletes should not see consistent and sufficient sleep merely as a lifestyle factor but rather as part of their overall training strategy, so that it gets the necessary attention. Field-deployable instruments like the PSQI and Bleep Test can provide for sport scientists and exercise physiologists an affordable and practical way of assessing sleep, endurance interrelationship in small club setups where sophisticated laboratory gear is not present. Lastly, sport psychologists might want to concentrate on the behavioral aspects that cause poor sleeping (e.g., using devices before going to bed, unpredictable and academic-related schedule changes) in order to enhance not only the athletes' recovery but also their mental readiness for the competition.

There are a number of limitations in this study that should be acknowledged. Since the sample size was small (n=10) and collected from a single swimming club, it is not only hard to detect statistically significant changes, but the results can also not be generalized to all adolescent swimmers. Also, the cross-sectional study design means that the sleep-endurance relationship is only measured once and thus it cannot identify causal direction or show changes in sleep and fitness of individual swimmers over a training cycle. Besides, sleep quality has been rated through self-report instead of objective actigraphy or polysomnography and endurance has only been estimated through a field test whereas direct gas-exchange measurement would be the preferable technique. It has been mentioned before that psychometric properties of the PSQI for use with athlete populations is under methodological scrutiny which could be the cause of an additional unquantified measurement error. Finally, there is still a percentage of unexplained variability (17.12%) that might be explained by other factors such as training load, nutrition, body composition, motivation and psychological readiness which were not included in the study.

Further research needs to make use of larger samples drawn from different clubs to raise the level of statistical power of such investigations and allow one to draw more general inferences from the results. The paper could also experiment with the longitudinal design or intervention (e.g., sleep hygiene programme), to study causal and dose-response relationships. Moreover, one should also consider objective sleep assessment tools like actigraphy. Lastly, the study should also take into account other covariates like training load, nutritional status and psychological readiness, so as to reduce the variability that remains unexplained in endurance capacity. The paper will be more complete if it considers club level studies measuring smartphone/digital device usage patterns. It will be useful to actually measure usage rather than relying on coaches' or players' reports. It is quite plausible that young athletes like those featured in this research group may be having sleep disturbances that are partly influenced by the devices' use. In the general population, adolescents' evening screen and smartphone use were significantly associated with poor sleep outcomes (Naing et al., 2024; Tkaczyk et al., 2023).

Conclusions

Sleep quality was measured by the PSQI and it was found to have a strong, negative and statistically significant relationship with cardiorespiratory endurance, which was measured from VO_2max by the Bleep Test amongst adolescent athletes of Women Swimming Club ($r=-0.910$, $p=0.00025$). Sleep quality accounted for a substantial 82.88% of the variance in endurance capacity ($R^2 = 0.8288$); this is an exceptionally large effect size rather than a limitation, although the remaining 17.12% of variance suggests that other factors, such as training load, nutrition, and psychological readiness, also contribute and merit further investigation. Good quality sleepers had more likely high endurance while poor sleeping people were more likely lower endurance. These findings should be interpreted in light of the study's small, single-club sample ($n = 10$) and cross-sectional design, which limit generalizability and preclude causal inference; nonetheless, they support incorporating sleep monitoring and education into training programmes for adolescent club-level swimmers.

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