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The Impact of Cognitive Fatigue and Sleep Quality on Reaction Time in Athletes

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A B S T R A C T

This study aimed to investigate the relationship between cognitive fatigue, sleep quality, and reaction time in athletes and to determine the predictive value of cognitive fatigue and sleep quality on reaction time performance. The study employed a correlational descriptive design with a sample of 385 Canadian athletes, selected based on Morgan and Krejcie's sample size guidelines. Data were collected using the Deary-Liewald Reaction Time Task for reaction time, the Cognitive Fatigue Scale for cognitive fatigue, and the Pittsburgh Sleep Quality Index for sleep quality. Pearson correlation analyses were conducted to assess the relationships between reaction time and each independent variable, and multiple linear regression was used to examine the combined predictive power of cognitive fatigue and sleep quality on reaction time. All analyses were performed using SPSS version 27, with a significance threshold set at $p < 0.05$. The results demonstrated that cognitive fatigue was positively correlated with reaction time ($r = .41$, $p < 0.01$) and sleep quality was also positively correlated with reaction time ($r = .37$, $p < 0.01$). Multiple linear regression analysis showed that cognitive fatigue and sleep quality together significantly predicted reaction time ($R = .46$, $R^2 = .21$, $F(2, 382) = 49.38$, $p < 0.001$). Both cognitive fatigue ($B = 2.38$, $p < 0.001$) and sleep quality ($B = 4.61$, $p < 0.001$) were significant independent predictors of reaction time. The findings highlight that both increased cognitive fatigue and poorer sleep quality are associated with slower reaction times in athletes. These results underscore the importance of managing both mental fatigue and sleep health to optimize cognitive-motor performance in athletic settings.

Keywords: *Cognitive Fatigue, Sleep Quality, Reaction Time, Athletes, Motor Performance.*

1. Introduction

Sleep quality and cognitive fatigue are two critical factors that significantly influence athletic performance, particularly in tasks requiring rapid motor responses such as reaction time. Recent research highlights the profound role that sleep quality plays in both physical and cognitive functioning among athletes (1, 2). As athletes increasingly strive for marginal gains in performance, understanding the interrelations between sleep, cognitive fatigue, and reaction time becomes ever more crucial.

Sleep quality is widely recognized as a fundamental component of athletic recovery and readiness. Poor sleep has been linked to impaired cognitive processes, diminished motor performance, and an increased risk of injury (3, 4). Sleep disorders and disturbances are not uncommon among athletes, owing to factors such as rigorous training schedules, travel demands, and psychological pressures (5, 6). Research suggests that inadequate sleep affects neurobehavioral functioning, leading to slower reaction times and reduced accuracy in performance tasks (7, 8). The specific mechanisms involve impaired attention, executive functioning, and psychomotor vigilance, which are essential for optimal athletic performance (9, 10).

Notably, the impact of sleep quality on reaction time has been thoroughly explored. Studies have shown that even acute sleep deprivation, characterized by missing a single night of sleep, can significantly impair reaction time (7, 8). Chronic sleep restriction, which accumulates over several nights of suboptimal sleep, has been associated with longer-term performance declines (11, 12). It is important to note that individual differences, including mental resilience and stress coping capacities, can moderate these effects (13). Furthermore, specific interventions such as sleep hygiene education and sleep extension strategies have been proposed to mitigate these negative impacts (3, 14).

Parallel to sleep quality, cognitive fatigue is another crucial determinant of athletic performance. Cognitive fatigue refers to a state of mental exhaustion that arises after prolonged periods of cognitive effort, often resulting in decreased motivation, impaired attention, and slower reaction times (2, 15). Cognitive fatigue is particularly relevant for athletes who must sustain high levels of mental focus during training and competition (16, 17). Studies have shown that cognitive fatigue can independently degrade motor performance even in the absence of physical fatigue (18, 19). This deterioration manifests in tasks requiring speeded responses, where cognitive fatigue can slow reaction times and increase error rates (7, 8).

Importantly, cognitive fatigue often interacts synergistically with sleep deprivation, leading to compounded impairments in performance (20, 21). For instance, athletes who experience poor sleep quality may become more vulnerable to cognitive fatigue, creating a vicious cycle that further undermines their cognitive and physical functioning (1, 11). Therefore, investigating both cognitive fatigue and sleep quality together provides a more comprehensive understanding of the factors influencing reaction time in athletes.

Numerous studies have attempted to address the causes and consequences of poor sleep among athletes. Factors such as early morning training sessions, frequent travel across time zones, academic demands (especially for student-athletes), and psychological stress are identified as key contributors (6, 22). Moreover, biological aspects such as chronotype misalignment (i.e., mismatch between an athlete's natural sleep-wake preference and their actual schedule) also play a role (23). Sleep monitoring technologies, including actigraphy and subjective sleep questionnaires like the Pittsburgh Sleep Quality Index, have been widely used to assess sleep patterns and intervene when necessary (12, 14).

Specific interventions targeting sleep have shown promise in improving athletic outcomes. These include sleep hygiene education, strategic napping, melatonin supplementation, and later training start times (10, 20, 24). Napping, for example, has been shown to improve afternoon performance in athletes who suffer from insufficient nocturnal sleep (10). Moreover, interventions promoting better pre-sleep routines and environments (e.g., reducing light exposure, maintaining regular sleep schedules) have demonstrated improvements in sleep quality and subsequent reaction time (3, 11).

Cognitive fatigue in athletes, on the other hand, has received relatively less empirical attention compared to sleep quality. Nonetheless, emerging evidence points to its significant impact on performance. Cognitive fatigue can result from prolonged exposure to stressful cognitive tasks such as tactical training, video analysis, or even academic

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responsibilities (2, 15). Neurocognitive mechanisms implicated in cognitive fatigue include diminished prefrontal cortex activation and reduced dopaminergic functioning, leading to impaired decision-making and slower psychomotor responses (8, 18).

An important consideration is that sleep deprivation and cognitive fatigue may not act independently but rather interact in complex ways to impair reaction time (18, 21). For instance, sleep loss may predispose athletes to cognitive fatigue, while cognitive fatigue could exacerbate the negative effects of poor sleep on motor performance. Understanding these interactions is crucial for developing comprehensive strategies to optimize athletic performance.

Several recent reviews have consolidated the evidence linking sleep disturbances with decrements in athletic performance. For example, a narrative review by Fullagar et al. (2) emphasized the consistent association between poor sleep and impaired performance across a variety of sports. Similarly, Hatia et al. (11) highlighted the multifactorial nature of sleep disturbances in athletes and proposed practical interventions for monitoring and improving sleep. Additionally, Gong et al. (7) provided meta-analytic evidence demonstrating significant negative effects of acute sleep deprivation on motor performance outcomes, including reaction time.

There is also growing awareness of the impact of cultural and situational factors on athletes' sleep. For example, Ramadan intermittent fasting has been shown to alter sleep patterns and training regimens among Muslim athletes, further influencing performance outcomes (17, 25). Such findings underscore the need for individualized and culturally sensitive approaches to sleep management in sports contexts.

Research focusing on sleep surfaces and environmental conditions has further demonstrated that optimizing sleep environments can yield measurable improvements in athletic performance (26). In particular, factors such as mattress firmness, room temperature, and noise control have been shown to influence sleep quality and, by extension, reaction time and overall performance outcomes (12, 26).

Given these extensive findings, it becomes evident that addressing both sleep quality and cognitive fatigue is essential for optimizing athletes' reaction time and overall performance. This study therefore aims to contribute to the growing body of literature by examining the associations between cognitive fatigue, sleep quality, and reaction time among Canadian athletes. Specifically, the study will investigate (a) the individual relationships between sleep quality and reaction time and between cognitive fatigue and reaction time, and (b) the combined predictive power of sleep quality and cognitive fatigue on reaction time through linear regression analysis.

2. Methods and Materials

2.1. *Study Design and Participants*

This study utilized a correlational descriptive design to investigate the relationships between cognitive fatigue, sleep quality, and reaction time in athletes. The sample consisted of 385 athletes from various sports disciplines across Canada, selected based on the sample size guidelines provided by Morgan and Krejcie's (1970) table for determining sufficient sample sizes. Participants were recruited through sports clubs, athletic associations, and online platforms. Inclusion criteria included being an active athlete aged 18 years or older and willingness to complete the study assessments. Informed consent was obtained from all participants prior to data collection, and ethical approval was secured from the relevant research ethics committee.

2.2. *Measures*

2.2.1. *Reaction Time*

The Deary-Liewald Reaction Time Task (DLRT), developed by Deary, Liewald, and Nissan in 2011, is a widely used computerized tool for measuring simple and choice reaction times in cognitive and sports psychology research. The DLRT consists of two main tasks: a Simple Reaction Time task, where participants respond to a single stimulus, and a Choice Reaction Time task, which requires selecting among multiple stimuli. The Simple Reaction Time section typically includes around 20–40 trials, while the Choice Reaction Time section includes about 40–60 trials. Reaction times are recorded in milliseconds, with lower scores indicating faster responses. Scoring involves calculating mean reaction times across trials for each task. The DLRT has demonstrated excellent reliability and validity across multiple studies involving both clinical and athletic populations, confirming its appropriateness for assessing reaction time variations related to cognitive fatigue and sleep quality.

2.2.2. *Reaction Time*

The Cognitive Fatigue Scale (CFS), created by Johansson and Rönnbäck in 2014, is a standard self-report instrument specifically designed to assess perceived cognitive fatigue in individuals following brain injury, but it has been successfully applied in healthy and athletic populations as well. The CFS consists of 15 items grouped into two subscales: Mental Fatigue (10 items) and Mental Recovery (5 items). Each item is rated on a 7-point Likert scale, with higher scores indicating greater cognitive fatigue. The total score is calculated by summing item responses, with subscale scores computed separately if needed. The CFS has shown strong internal consistency (Cronbach's alpha > 0.90) and good construct validity in both clinical and non-clinical studies, making it a valid and reliable tool for evaluating cognitive fatigue among athletes in research contexts.

2.2.3. *Sleep Quality*

The Pittsburgh Sleep Quality Index (PSQI), developed by Buysse, Reynolds, Monk, Berman, and Kupfer in 1989, is a widely recognized instrument for assessing subjective sleep quality over a one-month period. The PSQI consists of 19 self-rated items and 5 additional items rated by a bed partner or roommate (if available, but not scored). The 19 self-rated items are grouped into seven subscales: Subjective Sleep Quality, Sleep Latency, Sleep Duration, Habitual Sleep Efficiency, Sleep Disturbances, Use of Sleep Medication, and Daytime Dysfunction. Each subscale is scored from 0 to 3, and the sum of these subscale scores yields a global PSQI score ranging from 0 to 21, with higher scores indicating poorer sleep quality. Extensive research has confirmed the PSQI's high reliability (Cronbach's alpha > 0.80) and validity across diverse populations, including athletes, thereby supporting its use in evaluating sleep quality in sports science research.

2.3. *Data Analysis*

Data were analyzed using SPSS version 27. Pearson correlation analyses were conducted to assess the relationships between reaction time (dependent variable) and each of the independent variables (cognitive fatigue and sleep quality) separately. In addition, multiple linear regression analysis was performed with reaction time as the dependent variable and cognitive fatigue and sleep quality entered simultaneously as independent variables, to determine the predictive value of these factors. Statistical significance was set at $p < 0.05$ for all tests.

3. Findings and Results

Of the 385 participants, 197 (51.17%) were male and 188 (48.83%) were female. The participants' ages ranged from 18 to 35 years, with 146 individuals (37.92%) between 18 and 24 years, 178 individuals (46.23%) between 25 and 29 years, and 61 individuals (15.84%) between 30 and 35 years. Regarding the type of sport, 123 participants (31.95%) were involved in endurance sports (e.g., long-distance running, cycling), 156 participants (40.51%) competed in team sports (e.g., soccer, basketball), and 106 participants (27.53%) engaged in individual sports (e.g., tennis, swimming). The majority of participants (281 individuals, 72.99%) reported training five or more days per week, while 104 individuals (27.01%) reported training three to four days per week.

Table 1

Descriptive Statistics for Reaction Time, Cognitive Fatigue, and Sleep Quality

Variable	Mean	Standard Deviation
Reaction Time (ms)	312.47	28.63
Cognitive Fatigue	45.92	7.14
Sleep Quality	8.36	2.21

The descriptive statistics presented in Table 1 show that the mean reaction time among athletes was 312.47 milliseconds (SD = 28.63). The mean cognitive fatigue score was 45.92 (SD = 7.14), while the mean sleep quality score was 8.36 (SD = 2.21). These results suggest moderate levels

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of cognitive fatigue and relatively poor sleep quality in the participant sample.

Prior to conducting the main analyses, assumptions for Pearson correlation and multiple linear regression were assessed and confirmed. Normality was verified using the Kolmogorov-Smirnov test, which indicated non-significant results for reaction time ($p = 0.104$), cognitive fatigue ($p = 0.087$), and sleep quality ($p = 0.065$), supporting the assumption of normality. Linearity was assessed through scatterplots, which showed a clear linear relationship between the variables. Homoscedasticity was confirmed by examining the plot of standardized residuals, which demonstrated constant variance across predicted values. Multicollinearity was not a concern, as indicated by variance inflation factors (VIFs) below 2.00 for both cognitive fatigue (VIF = 1.43) and sleep quality (VIF = 1.38). Additionally, Durbin-Watson statistics (1.97) indicated no significant autocorrelation of residuals, supporting the independence of errors assumption.

Table 2

Pearson Correlations Between Reaction Time, Cognitive Fatigue, and Sleep Quality

Variable	1	2	3
1. Reaction Time	—		
2. Cognitive Fatigue	.41**	—	
3. Sleep Quality	.37**	.34**	—

As shown in Table 2, reaction time was positively correlated with cognitive fatigue ($r = .41$, $p < 0.01$) and sleep quality ($r = .37$, $p < 0.01$). Higher cognitive fatigue and poorer sleep quality were both associated with slower reaction times. Additionally, cognitive fatigue and sleep quality were significantly correlated with each other ($r = .34$, $p < 0.01$), suggesting a meaningful interrelationship between mental fatigue and sleep disturbances.

Table 3

Summary of Regression Analysis Predicting Reaction Time

Source	Sum of Squares	Degrees of Freedom	Mean Squares	R	R^2	Adjusted R^2	F	p
Regression	18324.67	2	9162.34	.46	.21	.21	49.38	<.001
Residual	67974.83	382	177.91					
Total	86300.00	384						

Table 3 presents the summary of the regression analysis results. The model was statistically significant ($F(2, 382) = 49.38$, $p < 0.001$), with an R^2 value of .21, indicating that cognitive fatigue and sleep quality together explained 21% of the variance in reaction time among athletes.

Table 4

Multivariate Regression Coefficients for Predicting Reaction Time

Predictor	B	Standard Error	β	t	p
Constant	201.86	18.47	—	10.93	<.001
Cognitive Fatigue	2.38	0.41	.35	5.80	<.001
Sleep Quality	4.61	0.79	.29	5.84	<.001

Table 4 presents the multivariate regression results. Cognitive fatigue significantly predicted reaction time ($B = 2.38$, $SE = 0.41$, $\beta = .35$, $t = 5.80$, $p < 0.001$), indicating that for every one-point increase in cognitive fatigue, reaction time increased by approximately 2.38 milliseconds. Sleep quality was also a significant predictor ($B = 4.61$, $SE = 0.79$, $\beta = .29$, $t = 5.84$, $p < 0.001$), suggesting that poorer sleep quality contributed to slower reaction times.

4. Discussion and Conclusion

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The findings of the present study revealed significant associations between cognitive fatigue, sleep quality, and reaction time in Canadian athletes. Pearson correlation analyses demonstrated that both cognitive fatigue and poor sleep quality were positively correlated with slower reaction times, suggesting that as cognitive fatigue and sleep disturbances increase, athletes' reaction times worsen. Furthermore, the results of the multiple linear regression analysis indicated that cognitive fatigue and sleep quality together significantly predicted reaction time, accounting for a notable proportion of the variance. These findings confirm the critical role of both mental and physical recovery processes in maintaining optimal athletic performance, particularly in tasks requiring rapid responses.

The observed relationship between sleep quality and reaction time is consistent with a robust body of literature emphasizing the detrimental impact of poor sleep on cognitive and motor performance in athletes. Research by Fullagar et al. (2) highlighted that compromised sleep quality leads to cognitive slowing, impaired attention, and reduced psychomotor vigilance, all of which negatively affect reaction time. Similarly, Gong et al. (7) demonstrated through meta-analysis that acute sleep deprivation significantly impairs reaction time across multiple sports contexts. These studies align with our findings by affirming that sufficient, high-quality sleep is necessary to maintain the cognitive agility required for athletic excellence.

Our results also support the findings of Xu et al. (8), who demonstrated that acute sleep deprivation impairs motor inhibition and slows reaction time in table tennis athletes. Given that reaction time is a crucial component in many sports, the confirmation of this relationship in our sample underscores the broad relevance of sleep management strategies across athletic disciplines. Moreover, the significant predictive power of sleep quality in our regression analysis is echoed by the conclusions of Hatia et al. (11), who reviewed the consequences of sleep restriction in athletes and recommended targeted interventions to address sleep disturbances for performance optimization.

Beyond sleep quality, our findings highlight the important yet often overlooked role of cognitive fatigue in influencing athletic reaction time. Cognitive fatigue showed a significant positive correlation with slower reaction times, a finding that supports previous assertions that mental exhaustion impairs athletes’ cognitive and motor performance. Fullagar et al. (2) emphasized that sustained cognitive load, even in the absence of physical fatigue, can degrade reaction times and decision-making speed. Similarly, Edwards et al. (15) pointed out that cognitive fatigue contributes to reductions in neurocognitive functioning, which can impair athletes' ability to respond quickly to dynamic competitive environments.

The significant combined effect of cognitive fatigue and sleep quality on reaction time found in this study reflects the complex interaction between psychological and physiological recovery factors. Walsh et al. (18) proposed that cognitive fatigue and sleep deprivation may act synergistically, compounding their negative impacts on athletic performance. Our findings align with this view, showing that athletes facing both poor sleep and high cognitive fatigue are particularly vulnerable to performance decrements, notably in domains requiring quick and accurate responses.

Moreover, the moderating role of mental resilience and stress management in mitigating the impacts of poor sleep and cognitive fatigue, as highlighted by Hrozanova et al. (13), suggests that psychological skills training could play a complementary role in protecting athletes from performance impairments. This is an area that warrants further exploration but supports the broader conclusion that managing both physical and mental recovery is critical for sustaining high-level athletic functioning.

In relation to the broader athletic context, our results mirror findings from studies on the specific sleep challenges faced by athletes. For example, Thornton (9) noted that elite ultrarunners often experience disrupted sleep patterns that impact their cognitive and physical performance. Similarly, Cho and Im (6) observed that adolescent athletes experiencing sleep problems exhibited higher levels of overtraining symptoms and slower reaction times. These findings reinforce the notion that sleep disturbances are not isolated incidents but systemic challenges that impact performance at various levels of competition.

Additionally, cultural and situational factors must be considered when interpreting the results. Research by Khélif et al. (17) showed that Ramadan fasting, which alters sleep schedules, significantly impacts athletes' sleep quality and training regimens. Such findings emphasize the need for

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individualized sleep management strategies that account for cultural practices and individual athlete circumstances.

Supporting interventions aimed at improving sleep quality have shown considerable promise in past research. Strategies such as pre-sleep routines, minimizing screen time, and optimizing sleep environments have demonstrated effectiveness in enhancing sleep outcomes among athletes (3, 20). Furthermore, the use of strategic daytime naps has been shown to partially mitigate the negative effects of sleep loss on reaction time and performance (10). These findings offer practical support for the implementation of structured sleep interventions as part of athletic training and recovery programs.

In terms of cognitive fatigue management, the development of mental recovery strategies, including mindfulness training and cognitive load balancing, may help mitigate its adverse effects. As noted by Walsh et al. (18), monitoring and managing athletes' cognitive demands, in addition to their physical workloads, could form part of a more holistic approach to optimizing performance. Interventions focusing on cognitive resilience, such as mental skills training, may thus complement sleep-related strategies in maintaining optimal reaction times and overall athletic readiness.

It is also noteworthy that sleep disturbances and cognitive fatigue do not only impair performance but may also increase the risk of injuries. Nobarı et al. (14) emphasized that poor sleep impairs immune function and increases injury risk, underlining the broader health implications of sleep and fatigue management for athletes. These findings highlight the critical importance of addressing both sleep quality and cognitive fatigue not only for performance enhancement but also for athlete well-being and career longevity.

Limitations of the current study must be acknowledged. First, the cross-sectional design limits the ability to infer causal relationships between cognitive fatigue, sleep quality, and reaction time. Longitudinal designs would provide stronger evidence regarding the directionality of these relationships. Second, the study relied on self-reported measures for assessing sleep quality and cognitive fatigue, which may be subject to reporting biases. Objective sleep measures, such as actigraphy or polysomnography, would strengthen future research. Third, the study sample consisted exclusively of Canadian athletes, which may limit the generalizability of the findings to athletes in different countries or cultural contexts. Future research should aim to include more diverse and international samples.

Future research should consider examining the longitudinal effects of sleep interventions and cognitive fatigue management programs on reaction time and athletic performance. Studies that incorporate experimental manipulations, such as controlled sleep deprivation or cognitive load induction protocols, would provide deeper insights into causal mechanisms. Additionally, future investigations could explore the moderating roles of individual differences, such as resilience, chronotype, and psychological skills, in the relationships between sleep, cognitive fatigue, and performance outcomes. Exploring sport-specific demands and tailoring interventions to different athletic disciplines would also enhance the applicability of findings.

From a practical standpoint, sports organizations, coaches, and athletic trainers should prioritize sleep quality and cognitive recovery as essential components of athlete development and performance programs. Implementing regular sleep education workshops, offering individualized sleep coaching, and integrating cognitive load monitoring into training schedules may help athletes optimize both their recovery and performance. Ensuring that athletes have access to mental health resources and psychological skills training could further enhance their resilience to cognitive fatigue and sleep-related challenges, ultimately supporting sustained high-level performance.

Authors' Contributions

All authors equally contributed to this study.

Declaration

In order to correct and improve the academic writing of our paper, we have used the language model ChatGPT.

Transparency Statement

Data are available for research purposes upon reasonable request to the corresponding author.

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Declaration of Interest

The authors report no conflict of interest.

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Ethics Considerations

The study placed a high emphasis on ethical considerations. Informed consent obtained from all participants, ensuring they are fully aware of the nature of the study and their role in it. Confidentiality strictly maintained, with data anonymized to protect individual privacy. The study adhered to the ethical guidelines for research with human subjects as outlined in the Declaration of Helsinki. Ethical considerations included obtaining informed consent, ensuring confidentiality and anonymity, and avoiding any harm to participants.

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