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Research article

Partial sleep deprivation affects the athletic performance of Sanda athletes: An RCT study

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ABSTRACT

This study explored the effects of partial sleep deprivation (PSD) on Sanda athletes' athletic performance, an area with limited research. Using a randomized crossover controlled trial with 18 male athletes, the PSD group had 4 h of sleep while the NSN group had 8 h. Results showed that after PSD intervention, the RAT time significantly increased compared to the NSN group ($P = 0.0311$). However, there was no significant change in CMJ ($P = 0.2396$) or YBT (left leg: $P = 0.2767$, right leg: $P = 0.3225$) between the PSD and NSN groups. In the Wingate test, the PSD group exhibited significant reductions in Pmax and Pave at 10s, 30s, and 60s ($P < 0.0001$), as well as a significant decrease in Prel at 60s ($P < 0.0001$), with no significant differences in Prel at 10s and 30s. These findings underscore the detrimental impact of limited sleep on anaerobic performance and agility in Sanda athletes, emphasizing the need for proper sleep management for optimal athletic outcomes.

1. Introduction

Sleep plays a crucial role in human physiological and psychological well-being and is often considered a vital aspect of athlete training and post-competition recovery. Sleep issues are particularly common among athletes, with a survey of 623 German athletes from various sports revealing that as many as 65.8 % have experienced poor pre-competition sleep quality at least once during their careers [1]. Similarly, a study focusing on 283 elite Australian athletes highlighted that 64 % of them experienced a decline in sleep quality before competitions [2]. Inadequate sleep can have detrimental effects on athletes, including decreased athletic performance, poor competition results, and increased risk of sports injuries [3], underscoring the necessity of maintaining consistent sleep duration and quality for both daily training and competitions among athletes.

Sleep deprivation (SD) refers to the reduction of a person's normal sleep duration or the disruption of their regular sleep pattern, leading to a decrease in sleep quality or insufficient sleep [4]. It can be classified into total sleep deprivation (TSD) and partial sleep deprivation (PSD). The negative impact of complete sleep deprivation on athletic performance and sports outcomes is evident. However, when it comes to partial sleep deprivation, its effects on athletic performance or sports outcomes become more complex and varied [5]. For instance, regarding muscle strength, some studies suggest that sleep deprivation has detrimental effects [6], manifested by a significant decrease in maximum weights lifted in exercises like bench press, leg press, and deadlifts [7]. However, other research argues that sleep deprivation does not significantly affect muscle explosive strength (both upper and lower body) [8] or sprinting

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abilities (including linear and agility sprints) [9]. When exploring the effects of sleep deprivation on athletic performance, it is essential to consider multiple factors and conduct specific analyses based on different sports disciplines and individual differences. Given that athletes are more likely to experience partial sleep deprivation in real-life scenarios, this is undoubtedly a matter worthy of high attention and concern. Partial sleep deprivation can be divided into partial sleep deprivation at the beginning of the night (PSD from 22:30 to 2:30) and partial sleep deprivation at the end of the night (PSD from 2:30 to 6:30). PSD at the end of the night typically encompasses a substantial portion of the rapid eye movement (REM) sleep phase, which is crucial for cognitive function and physical recovery [10]. During this period, REM and deep sleep stages are predominant, making sleep deprivation during this time likely to have a significant impact on athletic performance.

Martial arts Sanda, a traditional Chinese sports discipline, falls under the category of combat sports. In Sanda competitions, two individuals follow specific rules and employ techniques such as kicking, striking, and grappling from martial arts to overpower each other in unarmed combat. It is an essential competitive form of Chinese martial arts, demanding high levels of agility, lower-body explosiveness, balance, and anaerobic endurance, which are critical athletic abilities determining success in Sanda [11]. While numerous studies have explored the relationship between sleep and athletic performance, research specifically focusing on the acute effects of sleep deprivation on elite Sanda athletes is relatively scarce.

This study aims to investigate the impact of acute sleep deprivation on elite Sanda athletes' reactive agility, lower-body explosiveness, balance, and anaerobic performance through experimental interventions. It seeks to explore the relationship between sleep quality and athletic performance, providing scientific evidence and practical guidance for athlete training and competitive performance.

2. Materials and methods

2.1. Ethics statement

Ethical approval for this study was obtained from the Institutional Review Boards of Beijing Sport University with approval number of 2023347H (dated in 14-Mar-2023). Informed consent was obtained from all participants prior to their inclusion in the study. The clinical trial titled 'Partial Sleep Deprivation Affects the Athletic Performance of Sanda Athletes' was registered with the Chinese Clinical Trial Registry (ChiCTR) under registration number ChiCTR2400084831 on May 27, 2024.

2.2. Trial design

This study employed a crossover randomized controlled trial design to investigate the effects of acute 4-h sleep deprivation on

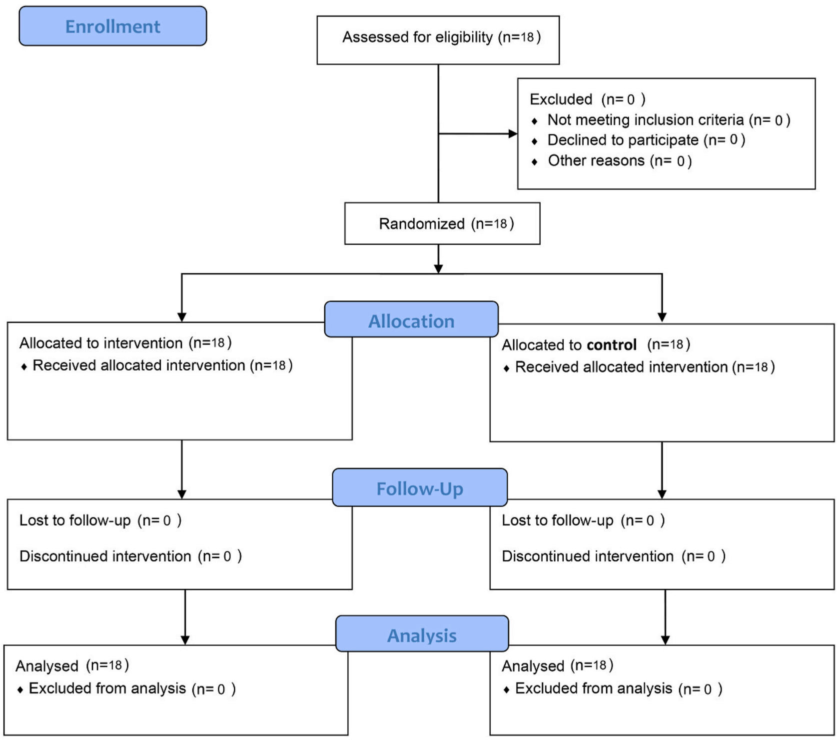

Fig. 1. Flow chart of participants in the study.

Sanda athletes' reactive agility, lower-body explosiveness, balance, and anaerobic performance. Random assignment was performed using a random number table. Participants were allocated in a 1:1 ratio to either the 4-h sleep deprivation intervention group or the control group (no intervention) using a crossover method. Measurements of the following dependent variables were taken before and after the intervention: reactive agility, counter movement jump, Y-balance, and Wingate test performance. The independent variables were time (before and after the 4-h intervention) and group (sleep deprivation intervention group and control group).

2.3. Participants

Using G*Power 3.1 software (Dusseldorf, Germany), the required sample size for the study was estimated in advance. Parameters were set based on previous literature to calculate the necessary sample size. The inclusion criteria for participants in this study were as follows: (1) Male Sanda athletes at the national first-class level or higher. (2) Participants were healthy, injury-free, maintained a normal diet, and did not smoke. (3) Participants were screened using the Pittsburgh Sleep Quality Index (PSQI) and the Epworth Sleepiness Scale. Participants were screened using the Pittsburgh Sleep Quality Index (PSQI) and the Epworth Sleepiness Scale. The recruited participants had no sleep disorders, maintained regular sleep patterns, and their average sleep duration was approximately 8 h. As shown in Fig. 1, a total of 18 male Sanda athletes were recruited for this study (age: 20.56 ± 2.17 years, height: 175.13 ± 6.25 cm, weight: 72.18 ± 9.76 kg, training experience: 8.73 ± 3.52 years).

2.4. Procedure

This study employed a crossover randomized controlled trial design (Fig. 2). Participants underwent familiarization with the experimental procedures and environment before commencing the formal experiment. During the formal experimental phase, each participant was required to complete two tasks: partial sleep deprivation (PSD group) and normal sleep nights (NSN group). The sleep duration was determined based on previous research [10,12]. For the PSD group, sleep duration was set at 4 h, from 2:30 a.m. to 6:30 a.m.; for the NSN group, sleep duration was set at 8 h, from 10:30 p.m. to 6:30 a.m. the next day. Each experimental session involved 9 participants for each task, with a washout period of 7 days before switching to the other task. The order of these two tasks was randomized and balanced to ensure an equal number of participants completed each type of task. During non-sleep periods, participants engaged in activities such as reading, playing board games, listening to music, and socializing, but avoided vigorous exercise or sleep. Throughout the intervention period, participants maintained a regular diet, refrained from alcohol, nicotine, and caffeine intake, avoided high-intensity exercise, and refrained from engaging in tasks involving high cognitive demands. Additionally, participants were instructed to maintain regular sleep habits at least three days before the experiment and avoid extra sleep during the intervention period.

The physical performance assessments were conducted before and after the PSD intervention. To minimize the impact of circadian rhythms on the experimental results, we made efforts to ensure that each participant underwent testing at consistent times, with deviations controlled within 1 h. The assessments were scheduled for 3:00 p.m. to simulate common competition finals, providing a more realistic reflection of athletes' physical condition during competitions. Before testing, participants engaged in a 2-min slow jog

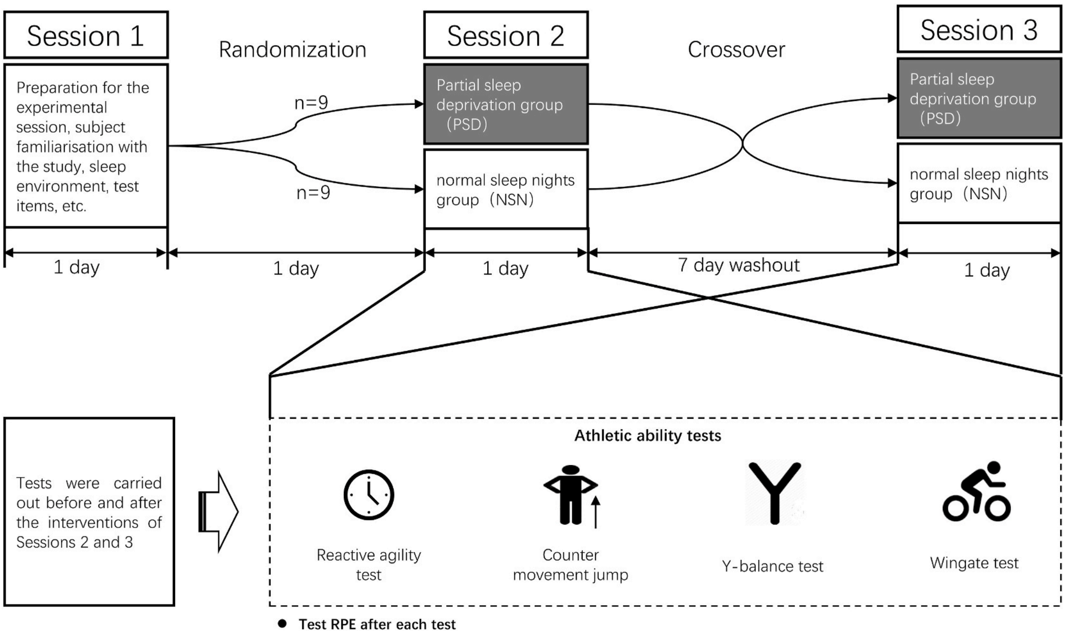

Fig. 2. Research workflow.

warm-up, followed by sequential completion of the reactive agility test (RAT), countermovement jump (CMJ), Y-balance test (YBT), and Wingate anaerobic power test indoors. Immediately after each test, we assessed their rating of perceived exertion (RPE). The experimental procedures were meticulously controlled, and the intervals between tests were carefully managed to provide participants with adequate rest, ensuring the accuracy and reliability of the results. During the intervals between tests, participants were allowed to sit quietly or engage in slow walking.

2.5. Measurements

2.5.1. Reactive agility testing

The measurement of reactive agility utilized the Reactive Agility Test (RAT), which involved the following procedure: Participants stood 0.5m behind the Smartspeed timing gates (Smartspeed Pro, Fusion Sport, Australia). Upon the "go" command, they completed the Y-shaped reactive agility test, consisting of a 5m sprint, followed by a 45° turn (left or right), and another 5m sprint, as quickly as possible. The direction of the turn was randomly determined by the trigger device (timing gates) placed at 2.5m, where the finish gates on the left or right side were randomly lit up upon activation. Participants had to react swiftly to the illuminated gate and sprint through it. Each sprint from start to finish constituted one trial, and a total of 6 trials were completed (3 left turns, 3 right turns), with a 30-s interval between trials (during which participants jogged or walked back to the starting point) to await the next trial. The shortest sprint time was used for analysis [13,14].

2.5.2. Countermovement jump testing

The Countermovement Jump test (CMJ) is used to assess lower limb explosiveness. The testing process is as follows: Before the test, participants performed a warm-up activity, which included jogging. During the test, participants stood with their hands on their hips on the Smartjump (Smartjump, Fusion Sport, Australia) mat, quickly squatting down to a 90° knee bend position while maintaining an upright torso. They then immediately jumped up explosively, with instructions to keep their torso as vertical as possible to minimize the impact of torso movement on the test results. In this study, participants performed 5 consecutive CMJ tests, with the first 2 serving to familiarize them with the movement, and the last 3 being formal tests. There was a 15-s rest interval between each CMJ test, during which participants remained standing. Participants were instructed to jump maximally during the tests, and the maximum jump height from the last 3 tests was used for analysis.

2.5.3. Y-balance test

The Y-Balance Test (YBT) is utilized to assess the balance capabilities of participants. Following the methodology from previous studies [15], the testing process is as follows: Participants stand barefoot on the Y-Balance Test device with hands on hips, balancing on one leg while using the toes of the non-supporting leg to slowly push three directional test boards as far as possible. The test is conducted in the order of supporting the right leg first, followed by supporting the left leg and measuring the maximum distance reached in three directions: anterior (A), posteromedial (PM), and posterolateral (PL). Each direction is measured three times, and the maximum distance reached is recorded for analysis. Upon completion of the tests, the comprehensive score for the YBT of both legs is calculated based on the distances reached in the three directions for each leg, using the formula: Comprehensive Score (%) = [(A + PM + PL)/(3 × lower limb length)] × 100, which is used to evaluate the participants' balance capabilities.

2.5.4. The Wingate test

The Wingate Test is utilized to assess the anaerobic capacity of participants. This test follows the methodology of previous studies and assesses the participants' anaerobic power at 10, 30, and 60 s. Specifically, participants engage in warm-up activities on a Monark power cycle ergometer (Model 894-E, Sweden) set at a 30-W load, aiming to achieve a heart rate of approximately 150–160 beats per minute. The warm-up period is controlled to last between 2 and 3 min. Before the test, the seat height and pedal straps of the ergometer are adjusted, and participants are given time to familiarize themselves with the upcoming workload. After a rest period of 3–5 min, the test officially commences. Upon the command "start," participants pedal the ergometer at maximum speed against a predetermined resistance (0.98 kg/1 kg of body weight) for durations of 10, 30, and 60 s. Participants receive strong verbal encouragement during the test to maintain the maximum pedaling rate. Following the exercise, data on maximum output power (Pmax), relative peak power (Prel), and average power (Pave) were collected. The calculation formulas are as follows: Pmax = force (kg) × distance (m)/time (s), Prel = Pmax (W)/body weight (kg), Pave = total work/(TW)time (s).

2.5.5. RPE test

The Borg Rating of Perceived Exertion (RPE) scale (0–10) was employed to assess subjective fatigue levels following each physical performance test (RAT, CMJ, YBT, and Wingate) to evaluate the impact of partial sleep deprivation on perceived exertion. The scale quantifies the perceived exertion based on the participant's sensations, such as heart rate, breathing, sweating, and muscle fatigue, providing a numerical representation (0–10) of exercise intensity [16].

2.6. Statistical analyses

The data obtained were subjected to statistical analysis using SPSS 26.0 software. Descriptive statistics for the data were presented in the form of mean ± standard deviation (M±SD). The paired-sample *t*-test was employed to analyze the differences in performance test scores between the PSD group and the NSN group. A two-way repeated measures analysis of variance (ANOVA) was conducted to examine the differences in RPE scores across different treatment levels. Mauchly's sphericity test was used to assess the assumption of sphericity for repeated measures ANOVA. If the assumption of sphericity was violated, the Greenhouse-Geisser correction was applied. Post-hoc pairwise comparisons were adjusted using the Bonferroni method. All statistical analyses were based on two-tailed hypothesis testing with a significance level set at $\alpha = 0.05$. Additionally, effect sizes were reported for the paired-sample t-tests (including post-hoc pairwise comparisons) as Cohen's d (d) and for repeated measures ANOVA as partial eta-squared ($\eta 2p$). The criteria for interpreting Cohen's d were as follows: <0.2, negligible; 0.2–0.6, small; 0.6–1.2, medium; 1.2–2.0, large; >2.0, very large [17]. For partial eta-squared ($\eta 2p$), the interpretation criteria were as follows: <0.04, no effect; 0.04–0.24, small effect; 0.25–0.63, medium effect; 0.64, large effect [18].

3. Results

3.1. *The impact of partial sleep deprivation on agility*

As shown in Fig. 3, regarding reactive agility (RAT), there was a significant increase in time for the PSD group ($t = 2.350$, $P = 0.0311$, $d = -0.5536$, 95 % CI = −0.1213 to −0.0065), indicating a decrease in reaction speed.

3.2. *The impact of partial sleep deprivation on countermovement jump (CMJ)*

For CMJ, there was no significant change observed between the PSD group and the NSN group ($t = 1.219$, $P = 0.2396$, $d = 0.2873$, 95 % CI = −1.137 to 4.248), indicating that sleep deprivation had no significant impact on vertical jump (Fig. 2).

3.3. *The impact of partial sleep deprivation on balance*

In terms of balance testing (YBT), there were no significant differences observed between the PSD and NSN groups for both left and right legs (left leg: $t = 1.124$, $P = 0.2767$, $d = -0.2649$, 95 % CI = −3.677 to 1.121; right leg: $t = 1.019$, $P = 0.3225$, $d = -0.2402$, 95 % CI = −3.412 to 1.189), suggesting that sleep deprivation had no significant effect on balance (Fig. 2).

3.4. *The impact of partial sleep deprivation on anaerobic capacity*

In the Wingate anaerobic performance test, the PSD group showed a significant decrease in maximal power output (Pmax) at 10s, 30s, and 60s (10s: $t = 5.692$, $P < 0.0001$; 30s: $t = 5.409$, $P < 0.0001$; 60s: $t = 7.923$, $P < 0.0001$). The relative maximal power output (Prel) at the 60s also significantly decreased ($t = 8.611$, $P < 0.0001$). Additionally, the average power output (Pave) at 10s, 30s, and

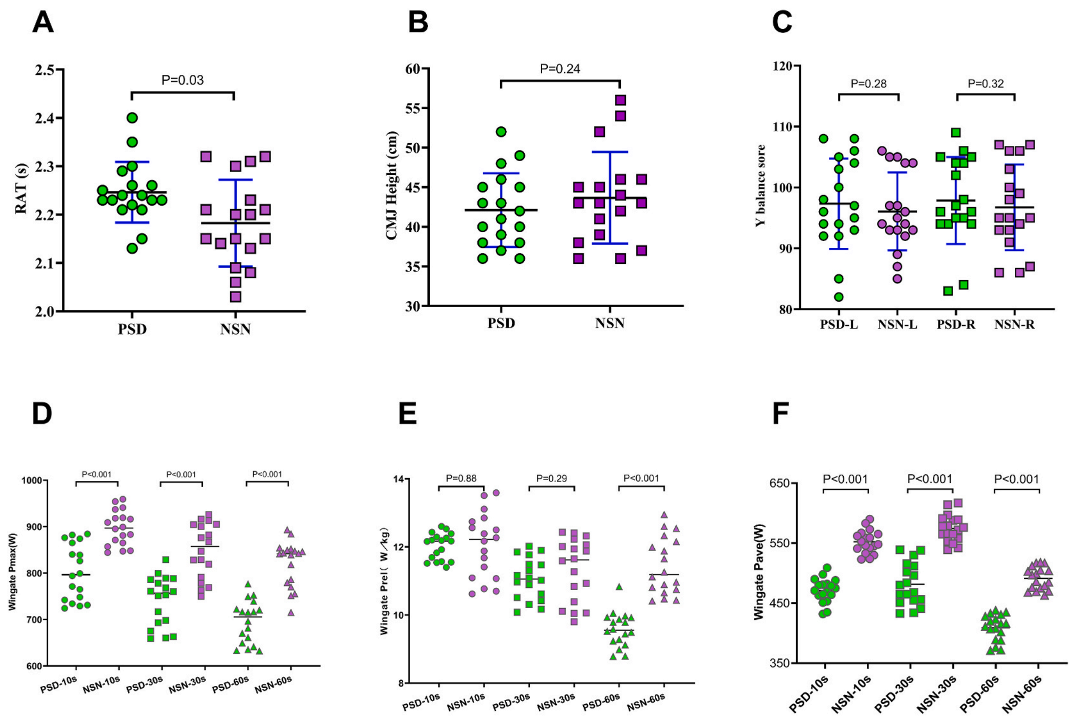

Fig. 3. Comparison of RAT, CMJ, YBT, and Wingate test scores between the PSD group and NSN group.

60s also significantly decreased (10s: t = 12.21, P < 0.0001; 30s: t = 8.306, P < 0.0001; 60s: t = 12.81, P < 0.0001) (Fig. 2).

3.5. *The impact of partial sleep deprivation on RPE*

In terms of subjective fatigue, the analysis of variance results showed that the main effect of intervention on RPE was not significant [F (1, 136) = 1.516, P = 0.2203, η2 = 0.0107], while the main effect of exercise duration on RPE was significant [F (3, 136) = 69.61, P < 0.0001, η2 = 1.4795]. The interaction between intervention and exercise duration was not significant [F (3, 136) = 1.193, P = 0.3150, η2 = 0.0254]. Separate effect analysis results (Fig. 4) showed that there were no significant differences in RPE scores after RAT (P = 0.1343, d = −0.3706, 95 % CI = −1.041 to 0.1519), CMJ (P = 0.2028, d = −0.3123, 95 % CI = −1.152 to 0.2634), YBT (P = 0.4268, d = −0.1920, 95 % CI = −0.9975 to 0.4420), and Wingate (P = 0.2307, d = 0.2929, 95 % CI = −0.2324 to 0.8990) tests between the PSD group and NSN group(Fig. 3).

4. Discussion

This study aimed to investigate the effects of partial sleep deprivation (PSD) on the reactive agility, lower limb explosive strength, balance ability, and anaerobic performance of elite martial arts Sanda athletes through experimental intervention. The study, for the first time, reported that PSD can decrease the reactive agility and the maximum output power (Pmax) and average power (Pave) in the Wingate test for 10s, 30s, and 60s, as well as reduce the relative maximum output power (Prel) in the 60s Wingate test among Sanda athletes. However, PSD had no significant impact on countermovement jump (CMJ), Y balance test (YBT), and the relative maximum output power (Prel) in the 10s and 30s Wingate tests.

In this study, PSD was found to decrease the reactive agility of Sanda athletes, manifested as an increase in reaction time. Previous research has reported a direct impact of sleep deprivation on individual agility. Studies have shown that after experiencing 24 h and 36 h of total sleep deprivation, participants exhibited a decline in agility performance, characterized by not only affecting the total time required for participants to complete agility tasks but also influencing the optimal performance time point they could achieve [19]. Reactive agility is a crucial ability determining the outcome of martial arts Sanda matches, comprising cognitive and directional factors [20]. Previous studies have mainly focused on the impact of sleep deprivation on the cognitive abilities of athletes in sports such as cycling, boxing, and soccer. The results revealed that athletes in a sleep-deprived state exhibited increased reaction time, decreased accuracy, and impaired decision-making ability when completing cognitive tasks, highlighting the negative impact of sleep deprivation on athletes' cognitive abilities [21]. Regarding directional ability, research has shown that soccer players took significantly longer to complete the 30-m sprint-turn test when sleep-deprived compared to their performance under normal sleep conditions [22]. Given that Sanda is a sport that demands high cognitive and directional abilities, the potential impact of PSD on cognitive and directional abilities may be a significant contributing factor to the notable negative impact of PSD on the reactive agility of Sanda athletes in this study. Studies have reported that PSD decreases cognitive ability and motor performance by reducing brain metabolism and slowing nerve conduction, particularly in the prefrontal cortex. PSD not only impairs cognitive function but also leads to prolonged reaction times and diminished decision-making capacity, likely due to decreased arousal levels in the central nervous system [23,24]. Furthermore, sleep deprivation can increase the fatigue level of the neuromuscular system, affecting nerve conduction velocity and muscle contraction force [25], which also influences athletes' agility and reaction speed. The disruptive impact of PSD is evident and holds significant implications for athletes, coaches, and managers, emphasizing the importance of addressing this issue.

Given the nature of Sanda sports, this study evaluated athletes' anaerobic performance during different periods using the 10s, 30s, and 60s Wingate tests. The results revealed that PSD decreased the 10s, 30s, and 60s Wingate maximum output power (Pmax) and average power (Pave) of Sanda athletes. Some studies align with our findings. For instance, research has shown that both 4-h and 24-h

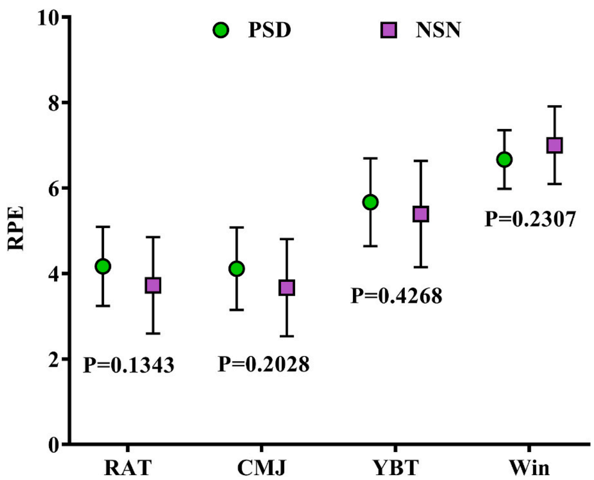

Fig. 4. Comparison of RPE between the PSD group and NSN group after AGT, CMJ, YBT, and Wingate tests.

sleep deprivation negatively impact the 30s Wingate peak power and average power in college students, with the effects being more pronounced after 24 h of sleep deprivation [26]. Another study involving 14 male taekwondo athletes subjected to 4-h sleep deprivation found decreased performance in repeat sprint running tests the following afternoon [10]. Additionally, complete sleep deprivation negatively affected the anaerobic performance of 24 elite kung fu athletes, as evidenced by tests measuring seated medicine ball throws (SMBT), horizontal jumps (HJ), and vertical jumps (VJ), among other indicators [17]. However, there is controversy regarding the impact of partial sleep deprivation on athletes' anaerobic performance the next day. Some studies report results that conflict with ours. For example, research investigating the effects of 4-h sleep deprivation on subsequent ultra-endurance exercise (evaluated using the 30s Wingate test) found changes in aspects such as ventilation, blood lactate levels, Wingate peak power, average power output, and peak speed [27]. Another study observed improvements in anaerobic performance in athletes in the morning after normal sleep and sleep deprivation; however, the improvement after normal sleep was greater than after sleep deprivation. This study also noted that 24 h of wakefulness did not affect anaerobic performance, but 36 h of sleep deprivation impaired anaerobic performance [6]. The reasons for these discrepancies may stem from individual variations in participant responses and differences in intervention methods. Some studies suggest that sleep deprivation may disrupt metabolic regulation, leading to inadequate energy supply or reduced energy utilization efficiency [28,29], affecting the operation of anaerobic metabolic pathways and reducing athletes' energy reserves and utilization efficiency. Furthermore, insufficient sleep can hinder proper bodily recovery, leading to accumulated fatigue [30], thereby affecting the function of muscles and the nervous system, and reducing athletes' explosiveness and endurance during anaerobic exercise. Several studies have also reported that PSD reduces the efficiency of glucose utilization in the brain, which in turn affects the neuromuscular function of athletes, subsequently impairing energy supply. This leads to a decline in performance during high-intensity anaerobic exercise, as evidenced by reductions in both maximum output power and average power [23,24]. These factors are potential contributors to PSD reducing the anaerobic performance of Sanda athletes.

This study found that PSD had no significant impact on Sanda athletes' CMJ height, balance ability, and RPE index. In this study, PSD did not significantly affect the CMJ height of Sanda athletes, indicating that PSD does not affect athletes' lower body explosiveness. Although research on the effects of sleep on CMJ or explosiveness is limited, some studies have reported that soccer players experienced a decline in CMJ after sleep restriction but with no significant differences [31], which is consistent with the results of this study. Additionally, PSD's impact on CMJ in this study did not show significant differences. Previous research has shown that complete sleep deprivation can lead to a decrease in CMJ performance among rugby players [32], suggesting that extending the duration of PSD may indeed affect CMJ in Sanda athletes.

In terms of balance ability, this study also found that PSD had no significant impact on the balance ability of Sanda athletes. However, existing research on the relationship between PSD and balance ability is relatively limited. Some studies suggest that poor sleep quality is associated with a decline in balance control ability among university students [33], and partial sleep deprivation of 4 h can also lead to decreased scores in static and dynamic balance tests for male university athletes [26]. Additionally, a study involving judo athletes as subjects indicated that 4 h of sleep deprivation had a significant negative impact on the posture control of judo athletes [34]. Therefore, further experimental designs are needed to explore whether longer periods of PSD may have potential effects on balance ability.

Furthermore, this study also found that PSD had no impact on the RPE (subjective perception of fatigue) index. Overall, although the effects of PSD in certain aspects are not significant, considering its potential impacts on other aspects of athletes, future research needs to delve deeper into the relationship between PSD and the performance of Sanda athletes.

4.1. Practical applications

The findings of this study highlight the negative impact of partial sleep deprivation (PSD) on athletic performance, particularly in areas such as anaerobic power and agility. To help athletes and coaches mitigate these effects, several practical strategies can be implemented. First, athletes should prioritize consistent sleep schedules, aiming for at least 7–9 h of sleep per night to optimize recovery and performance. For those facing unavoidable sleep disruptions, such as during travel or competition schedules, short naps and controlled relaxation techniques (e.g., meditation or breathing exercises) can help alleviate the effects of sleep loss. Coaches can also structure training sessions to accommodate periods of reduced performance due to fatigue, ensuring adequate recovery time after intense physical or mental stress. Monitoring both sleep quality and duration using wearable devices may also help track sleep patterns and ensure athletes are adequately rested before competitions.

By implementing these strategies, athletes and coaches can better manage the challenges of sleep deprivation and maintain optimal performance in both training and competition.

4.2. Limitations of the study

This study has several limitations. Firstly, the duration of sleep deprivation in this study was set at 4 h. Future studies should explore various durations of sleep deprivation, including chronic partial sleep deprivation, to better understand its long-term impact on both cognitive and physical performance. Secondly, while this study utilized RAT, CMJ, Y-balance, and Wingate anaerobic capacity tests to assess athletic performance, these measures may not comprehensively capture the broader spectrum of athletic capabilities, such as cognitive function, decision-making, or tactical skills, which can be significantly affected by sleep deprivation. Thirdly, the sample in this study consisted of male athletes, which limits the generalizability of the findings. Future research should increase the sample size and include athletes of different genders and ages to enhance the reliability and applicability of the results across a broader athletic population.

5. Conclusions

A 4-h PSD intervention reduces the anaerobic capacity and agility of Sanda athletes while not affecting balance and lower limb explosive power.

Data availability statement

The data that support the findings of this study are available on request from the corresponding author (TM: meitao@bsu.edu.cn).

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CRediT authorship contribution statement

Liang Li: Writing – original draft, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Tao Mei:** Writing – review & editing, Writing – original draft, Visualization, Supervision, Project administration, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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