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# Single and Combined Effect of Acute Sleep Restriction and Mental Fatigue on Basketball Free-Throw Performance

**Luca Filipas, Davide Ferioli, Giuseppe Banfi, Antonio La Torre, and Jacopo Antonino Vitale**

***Purpose**:* This study aimed to investigate the single and combined effects of sleep restriction (SR) and mental fatigue (MF) on free-throw (FT) performance among adult male basketball players. ***Methods**:* A total of 19 amateur male basketball players performed, in a randomized, counterbalanced, and crossover order, 2 identical experimental sessions separated by an interval of 1 week. The difference between the 2 sessions was in the quantity of sleep the night before the sessions, as follows: in one case, the participants followed their habitual sleep–wake routines; in the other session, they were forced to sleep not more than 5 hours. During the experimental sessions, the participants performed 60 basketball FTs on 2 occasions, separated by watching a basketball tactical video for 30 minutes designed to induce MF. As such, the FT test was completed in 4 different conditions: control, MF, SR, and SR and MF combined. ***Results**:* The participants registered a significantly lower total sleep time in acute SR ($P < .001$). The subjective rating of MF was lower in the control than in MF, SR, and SR and MF combined ($P < .001$). There were no differences between conditions for the subjective ratings of motivation. FT accuracy was higher in the control than in MF, SR, and SR and MF combined ($P = .010$), while no differences were observed between the 3 experimental conditions (all $P > .05$). ***Conclusion**:* The results indicate that a combined effect of MF and SR induces a *small* reduction in basketball FT performance, similar to MF or SR alone.

***Keywords**:* team sports, technical demands, free-throw accuracy, sleep loss

Basketball is a physically demanding team sport[1] requiring a high degree of technical skills during both offensive and defensive situations.[2,3] A free throw (FT) is a technical element of basketball resulting from a single foul penalty during game evolution. FTs are commonly shot from the FT line without any defensive pressure and provide players with the opportunity to score 1 point for each successful FT. Scoring FTs with high accuracy is a key determinant to success in basketball, in particular in close games.[4] Accordingly, basketball games typically include several FTs, accounting for a large share of all scoring (ie, approximately 20%–30%).[5] Thus, developing strategies to enhance an FT scoring percentage and understanding adverse factors that negatively affect FT accuracy might result in a greater chance of winning a game.

Sleep is a biological process having several cognitive and physiological functions that are essential for recovery and performance in elite athletes.[6] Nonetheless, athletes often experience and report inadequate sleep,[7,8] and for this reason, the International Olympic Committee has recently outlined the importance of obtaining sufficient sleep quantity and quality to promote global development and health among athletes.[9] The negative effect of sleep restriction (SR) or deprivation on some athletic performances, especially on tactical decision making, motor coordination, and aerobic physical effort, is now well documented.[10–12] Although the negative effect of SR has been documented in team sports,[13] few studies investigated this aspect in basketball. Jones et al[14] found that late-night Twitter activity was associated with negative changes in next-day game performance among professional National Basketball Association athletes. Specifically, it was observed that National Basketball Association players who registered late-night Twitter activity contributed fewer points and rebounds and decreased their shooting accuracy too; however, particularly noteworthy is that athletes' sleep was not actually measured in this study and only late-night tweeting was used as an indirect measure of SR.[14] Staunton et al[15] assessed the association between sleep and match performance, evaluated with the basketball efficiency statistic, in elite female basketball players. The results showed moderate negative to large positive correlations, highlighting a very large degree of interindividual variability in the relationship between sleep and match performance.[15] Furthermore, Mah et al[16] observed clear improvements in college students' shooting accuracy, with their FT percentage increasing by 9% during a sleep-extension period (ie, +110 min than their habitual sleep–wake schedule). Thus, these results highlight the importance of following correct sleep routines to preserve or enhance basketball technical performance (eg, shooting accuracy). Despite these studies providing preliminary insights, further research is required to better understand the effect of acute SR on technical performance in basketball.

Acute mental fatigue (MF) is defined as a psychobiological state that may arise during or after prolonged cognitive activities; it is characterized by feelings of tiredness or even exhaustion, and a decreased commitment and increased aversion to continue the current activity.[17] Acute MF has an adverse effect on cognitive function[18,19] and endurance exercise performance.[20] Recent research has also revealed that the MF state is a key regulator of technical performance of youth basketball players, reducing small-sided games performance and altering neuroendocrine and autonomic responses.[21] Specifically, the authors observed an increase in the total number of turnovers when the players were mentally fatigued. However, no further details were provided regarding the other technical elements that were analyzed collectively as player's efficiency. Furthermore, FTs were not allowed during the small-sided games, thus limiting the understandings of

Filipas, Ferioli, and La Torre are with the Dept of Biomedical Sciences for Health, Università degli Studi di Milano, Milan, Italy. Banfi, La Torre, and Vitale are with the IRCCS Istituto Ortopedico Galeazzi, Milan, Italy. Banfi is also with the Vita-Salute San Raffaele University, Milan, Italy. Vitale (jacopo.vitale@grupposandonato.it) is corresponding author.

the effect of MF on shooting accuracy and other technical elements. A thorough understanding of the effect of MF on basketball technical performance, especially among adult players, is still required. This information may provide useful insights for basketball practitioners to better manage and plan typical events that may induce MF before training and competitions (eg, video sessions with coaching staff or a prolonged use of smartphones/electronic devices).

The MF and SR are conditions that may occur (independently or in combination) before basketball practice in both amateur and elite players. Advancing an understanding of the impact of MF and SR on basketball technical performance may have relevant implications for developing strategies to overcome their potential detrimental effects during matches. Therefore, the aim of this study was to determine the single and combined effect of SR and MF on FT performance among adult male basketball players. The authors hypothesized that there would be a significant decrement in FT accuracy when players are mentally fatigued and forced into acute SR.

# Methods

## Subjects

A total of 19 amateur adult male basketball players (age = 20 [3] y, stature = 184 [6] cm, body mass = 82 [6] kg, body mass index = 24.1 [3]) voluntarily participated in this study. All participants were recruited from 3 separate basketball teams competing at regional level (Italian sixth division). Throughout the data collection period, the players completed 1 game and 2 to 3 training sessions per week. All players included in this study were practicing basketball for at least 3 years and successfully completed the required preexercise screening before the commencement of the study. The exclusion criteria included having any medical condition or injury that prohibited the participants from being able to complete the physical and technical components of the study, having a diagnosed sleep disorder or <7 hours of sleep per night in the normal period, melatonin consumption or known color-vision impairments. All participants provided written informed consent before participation. All procedures were approved by the Ethical Committee of the University of Milan and followed the ethical principles for medical research involving human subjects set by the World Medical Association Declaration of Helsinki.

## Design

The protocol was carried out in a randomized, counterbalanced, and crossover order. The participants visited the respective testing facilities on 3 separate occasions, with the first visit functioning as a familiarization session. The remaining 2 visits were performed in a randomized and counterbalanced order generated by online software (ww.randomization.com). The playing positions were similarly represented in all groups to avoid potential bias effects of playing position on the outcome variables.[22] The researchers assessing the outcome measures were not blinded to treatment but were instructed not to provide any kind of information to the participants. The participants were told that the study sought to compare the effects of MF and acute SR on FT performance. Prior to each visit, the participants were instructed to refrain from the consumption of alcohol and caffeine and to avoid any vigorous exercise the day before the testing. The participants were also instructed to avoid any mentally demanding tasks the day of the testing sessions. Compliance with these instructions was assessed with pretest checklists upon arrival for the testing sessions. Each participant carried out the visits individually, at the same time of day (within a 1-h period, between 9:00 and 11:00 AM for the testing sessions) and separated by 1 week. All the testing sessions were performed at a temperature of 22°C (4°C).

## Methodology

An overview of the experimental procedures is shown in Figure 1. After the first visit for familiarization with all the testing procedures, the participants completed the 2 experimental sessions. The procedures of each session were the same, with the only difference being the quantity of sleep the night before the sessions: in one case, the participants were instructed to sleep following their habitual sleep–wake routines and behaviors; in the other session, they were restricted to sleep ≤ 5 hours (see "ActiGraph Monitoring and Acute SR" section for further details). During the 2 visits, the participants performed a 5-minute standardized warm-up, including basketball-specific running exercises, basketball technical elements, and a series of 5 FTs (practice trial), followed by a FT basketball test. After the test, the participants watched a basketball tactical video for 30 minutes, aiming to induce MF (see "MF Task" section for further details). Immediately after the mental fatiguing task, the participants completed the second FT basketball test. The subjective level of MF and motivation were assessed before the 2 FT tests with a visual analogue scale. As such, the FT test was completed in 4 different conditions: control (CON), MF, SR, SR and MF combined (SRMF).

***ActiGraph Monitoring and Acute SR.*** All subjects wore a wrist activity monitor, the Actiwatch 2 actigraph (Philips Respironics,

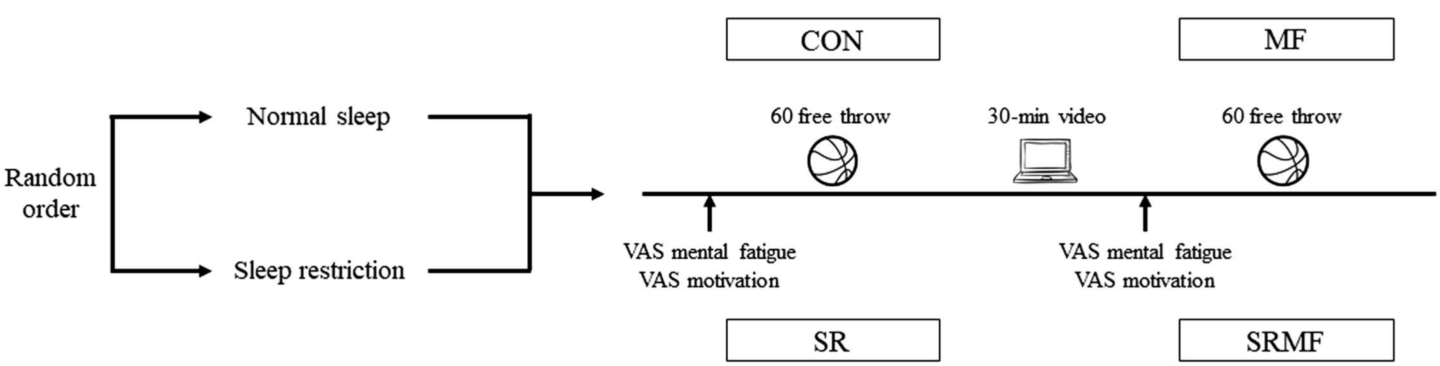


**Figure 1** — Overview of the 2 experimental visits. CON indicates control; MF, mental fatigue; SR, sleep restriction; SRMF, sleep restriction and mental fatigue; VAS, visual analog scale.

Portland, OR), to record their sleep parameters for 2 consecutive weeks. A high actigraphic sensitivity threshold (80 activity counts) was selected to detect sleep parameters.[23] Together with the actigraph, each subject received a sleep diary to record their bedtime, wake-up time, hours napping, and the number of nocturnal awakenings. The data derived from the sleep diaries and wrist activity monitors were used to determine the amount and quality of sleep the participants obtained. Specifically, 9 sleep parameters were measured, as follows: (1) bedtime, the self-reported time at which a participant went to bed to attempt to sleep; (2) get-up time, the self-reported time at which a participant got out of bed and stopped attempting to sleep; (3) time in bed, the amount of time spent in bed attempting to sleep between bedtime and get-up time; (4) sleep onset, the time at which a participant first fell asleep after going to bed; (5) sleep offset, the time at which a participant last woke before getting up; (6) sleep efficiency, the percentage of time in bed actually spent sleeping; (7) sleep latency, the period of time between bedtime and sleep onset time; (8) total sleep time, the number of minutes of sleep obtained during a sleep period; and (9) fragmentation index, the sum of the time spent moving and the immobility phases of 1 minute, both expressed in percentage, divided by the number of immobility phases.

The night before 1 of the 2 FT sessions, the subjects were forced into acute SR; specifically, they were requested to set the alarm clock exactly 5 hours after bedtime. The participants were instructed to abstain from falling asleep again or having a nap and to avoid any kind of physical exercise before the morning testing session.

***MF Task.*** The MF conditions consisted of watching 30-minute tactical basketball videos. The videos were created based on the tactical level of the participants, leading to a full comprehension of the tactics explained in the video. The authors decided to choose a more applied approach to MF following the recommendation of a recent review on this topic.[24] After the videos, the participants were instructed to respond to 12 questions to check their attention to the videos. The videos required sustained attention; thus, they were supposed to induce MF. The participants completed the mentally fatiguing task in a quiet room, under the supervision of the same researchers. The participants' subjective assessments of perceived workload were recorded using visual analogue scales. A visual analogue scale was used to assess the perceptions of MF and motivation toward the upcoming technical tests.[20]

***FT Basketball Test.*** The FT test consisted of shooting 60 consecutive FTs from the standard FT line (4.6 m, FT line distance from point on floor directly below backboard) on a regular basketball court (hoop height, 3.05 m) using a standard basketball ball (Molten GG7, 600 g). The participants were instructed to score the maximum number of FTs possible (out of 60 attempts), shooting within 5 seconds (according to the International Basketball Federation rules) after receiving a pass from a partner not participating in the trial.[25] The FT score at the end of each block of 20 shots and overall score were recorded during the tests. No motivational intervention or technical feedback on the FTs shots was provided by the researchers and coaching staff.

## Statistical Analysis

All data are presented as mean (SD). Prior to the analysis, the Shapiro–Wilk test and the Mauchly test were employed to test the normality of the data and sphericity assumption, respectively. When sphericity was not met, the Greenhouse–Geisser correction was used to adjust the significance of the *F* ratios. The Actigraph sleep parameters from the 2 nights preceding the testing sessions were compared using the paired *t* tests. One-way repeated-measures analysis of variance (ANOVA) was used to determine the differences between the 4 conditions in the overall FT score and in the perceptions of MF and motivation toward the upcoming technical tests. The FT score during the 4 interventions was also averaged in blocks of 20 shots and analyzed with a 2-way fully repeated-measures ANOVA ($4 \times 3$) to determine the effect of condition and time. In addition, a mixed $2 \times 4$ ANOVA with the visits order listed as the between-subject factor and the condition as the within-subjects factor was used to exclude a learning effect on the performance and bias in the ratings of the psychological questionnaires after the interventions. Significant main effects and interactions, when more than 2 levels were employed, were interpreted through pairwise comparisons with Bonferroni correction. Significance was set at .05 (2-tailed) for all analyses. The effect sizes for repeated-measure ANOVA are reported as partial eta squared ($\eta_p^2$), using the small (<.13), medium (.13–.25), and large (>.25) interpretation for effect size,[26] while effect sizes for pairwise comparison were calculated using Cohen *d* and considered to be either trivial (effect size: <0.20), small (0.21–0.60), moderate (0.61–1.20), large (1.21–2.00), or very large (>2.00).[27] The data analysis was conducted using the Statistical Package for the Social Sciences, (version 25; SPSS Inc, Chicago, IL).

# Results

## Sleep Restriction

The subjects had a total sleep time of 7.3 (0.7) hours the night before the testing session with the normal sleep-wake routines, while, the night before the second testing session, with forced acute SR, the participants registered a significantly lower total sleep time (4.6 [0.3]; $P < .001$). The get-up and sleep offset times occurred, as expected, significantly earlier in the morning after acute SR ($P < .001$). In contrast, all other sleep quality and quantity parameters were similar in the 2 conditions.

## Manipulation Checks

Accuracy of the comprehension questions after the video was 95% (8%) in MF and 93% (9%) in SRMF. Figure 2 shows the subjective ratings of MF (A) and motivation (B) in the 4 conditions. There was a significant difference between conditions for subjective ratings of MF ($F_{1,18} = 16.616$, $P < .001$, $\eta_p^2 = .48$, *large*). MF was lower in CON than in MF ($P < .001$, $d = 1.71$, *large*), SR ($P = .002$, $d = 1.33$, *large*), and SRMF ($P < .001$, $d = 1.75$, *large*). There were no differences between conditions for subjective ratings of motivation ($F_{1,18} = 0.384$, $P = .765$, $\eta_p^2 = .02$, *small*). No significant effects of session order existed for the subjective ratings of MF and motivation.

## Technical Performance

Table 1 reports the FT score in the 3 different blocks of 20 shots. There was a significant difference between conditions for FT performance ($F_{1,18} = 4.177$, $P = .010$, $\eta_p^2 = .19$, *medium*). FT accuracy was higher in CON than in MF ($P = .015$, $d = 0.41$, *small*), SR ($P = .021$, $d = 0.43$, *small*), and SRMF ($P = .019$, $d = 0.41$, *small*), with a decline in performance of approximately 7% in all 3 conditions. There were no effects of time ($F_{1,18} = 0.223$, $P = .801$, $\eta_p^2 = .02$, *small*) and condition × time ($F_{1,18} = 0.066$, $P = .999$,

$\eta_p^2 = .01$, *small*) for these scores. No significant effects of session order existed for the FT basketball test.

## Discussion

The present study provides novel insights into the single and combined effect of SR and MF on FT performance among adult male basketball players. The main finding of the present study was that FT accuracy was slightly impaired in MF (*small*), SR (*small*), and SRMF (*small*) compared with CON. The level of impairment was the same in the 3 intervention conditions. Moreover, a higher subjective rating of MF was reported in MF (*large*), SR (*large*), and SRMF (*large*) compared with CON, with no differences between conditions for self-reported level of motivation. As already highlighted in the literature,[15,21] MF and SR may negatively affect technical performance in basketball. The results of this study are relevant, as understanding the adverse factors that negatively affect the accuracy of FTs may result in a greater chance of winning a game. Indeed, it has been reported that FTs account for approximately 20% to 30% of all game scoring.[5] Accordingly, scoring FTs with high accuracy is a key determinant to success in basketball, especially during close games.[4]

For the first time, the results of the present study show a small but significant decrease in FT scores after MF and acute SR, highlighting the negative effects of these 2 situations on a specific basketball task. Moreover, to the best of our knowledge, no studies have evaluated the effect of a combination of MF and SR on technical performance yet. Their combination led to a similar reduction in FT accuracy (ie, overall and blocks of 20 FTs) compared with the single effect of MF and SR. It should be considered that differences in FT accuracy between CON and experimental conditions (ie, MF, SR, and SRMF) were *small*. However, from a practical point of view, an approximate 7% reduction in FT accuracy may negatively affect the total game score, thus reducing the chance of winning a game, especially in close games.

A reduction in motor CON could be the result of acute MF or SR and, therefore, generate a decrease in basketball FT performance.[28] The physiological explanation for this reduction in technical performance is yet unknown, but it may be attributed to an increment in distractibility, difficulty in sustaining attention, and ignoring irrelevant information.[29] Another possibility lies in the lower testosterone levels after MF and sleep loss compared with a CON condition found in recent studies.[21,30] This might affect dopaminergic transmission to brain areas concerned with cognitive CON, which ultimately could result in individual increased technical errors. This dopaminergic pathway via testosterone modulation has been found in animal studies and considered valid also in humans.[31]

Considering the lack of further impairment in performance after the combination of MF and acute SR, an explanation for this result is hard to be proposed because no other studies have combined 2 cognitive stressors in the evaluation of their effect. A recent study showed that MF did not reduce the physical performance of young rowers, with the experimental sessions performed on school days from 14:00 to 18:00. The MF accumulated at school could have mitigated the detrimental effect of the cognitive task used to induce MF in the experimental sessions.[32] Similarly, in the present research, the reduction in sustained attention, determined by acute SR,[33] could have mitigated the effect of the following mental fatiguing task.

For the first time, an ecological approach in the induction of MF was chosen for this study: a video on basketball tactics was used, which has been effective in inducing MF in participants. This is of relevant interest, as a common practice in basketball is to perform video sessions analyzing games, tactical actions, and opponents' game strategies before practice or game sessions. As such, practitioners should consider that including long-lasting video sessions may induce MF, thus impairing technical performance in the

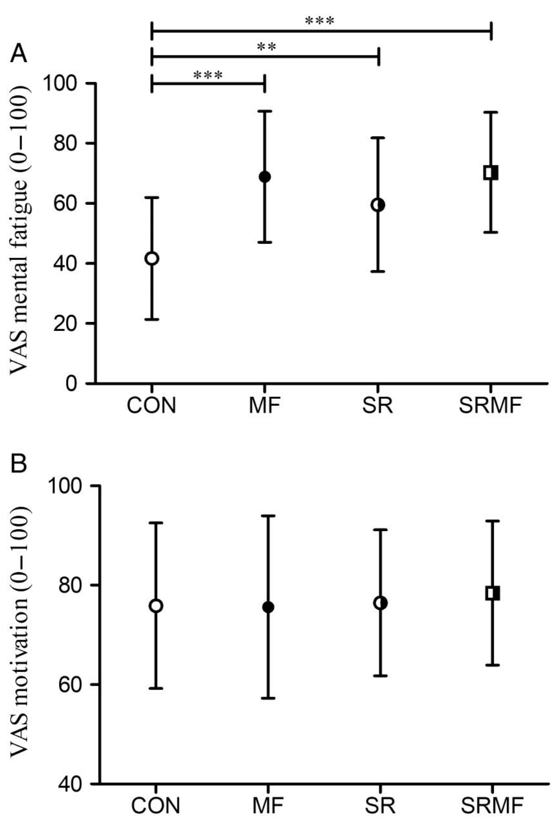


**Figure 2** — Effect of 4 different conditions on subjective ratings of mental fatigue (A) and motivation (B). CON indicates control; MF, mental fatigue; SR, sleep restriction; SRMF, sleep restriction and mental fatigue; VAS, visual analog scale. **Significant difference between the conditions ($P < .01$). ***Significant difference between the conditions ($P < .001$). Data are presented as mean (SD).

**Table 1 Effect of 4 Different Conditions on FT Performance Divided in Blocks of 20 Shots**

| Condition | FT score (1–20) | FT score (21–40) | FT score (41–60) | FT score (overall) |
|---|---|---|---|---|
| Control | 14.3 (2.7) | 14.4 (2.7) | 14.4 (3.1) | 43.2 (7.1) |
| Mental fatigue | 13.5 (3.1) | 13.4 (3.9) | 13.3 (3.5) | 40.1 (7.7) |
| Sleep restriction | 13.4 (3.5) | 13.7 (2.2) | 13.2 (2.8) | 40.2 (6.5) |
| Sleep restriction and mental fatigue | 13.2 (3.5) | 13.5 (2.9) | 13.2 (3.3) | 40.0 (8.6) |

Abbreviation: FT, free throw. Note: Data are presented as mean (SD).

upcoming practice/game session. Future studies on MF should use a similar ecological approach to make the experimental session more similar to what happens in a real basketball match.

Despite the robustness of the current findings, some limitations should be highlighted, and caution is recommended concerning the generalization of the present results. The authors acknowledge the limitation of dividing the protocol in 2 experimental sessions instead of 4, given the 4 experimental conditions. This decision was made to standardize the hours of sleep in the normal sleep and SR conditions to avoid bias derived from a different sleep duration in each visit. Hence, the authors previously tested the test–retest reliability of 2 consecutive FTs sessions, and it has been reported to be very high (intraclass correlation coefficient = .98). Another limitation is that the video duration might be considered a quite short cognitive load, which in turn, could reduce the likelihood of inducing an extreme MF. However, the current data together with the results from previous studies[24,34] suggest that the proposed MF and SR led to fatigue in the evaluated players.

## Practical Applications

The findings of this study are important for coaches and professionals who are responsible for the planning and execution of training programs and pregame preparation. Athletes should avoid cognitive efforts or SRs before training sessions and matches to prevent negative effects on their technical performance. This could be even more important for amateur players, because they suffer from MF daily at school or at work and could experience this condition more often than professional players. Future experimental research should investigate the effect of chronic MF and SR on basketball technical performance to determine if the *small* differences between conditions can differ from long-term interventions. Another future perspective could be to compare these results with a similar study conducted on professional athletes, where the technical consistency is higher than that for amateur athletes.

## Conclusion

The present study highlights that FT accuracy can be slightly impaired by MF and SR. Furthermore, a combined effect of MF and SR reduces FT performance similarly to their single effects. These data highlight the need to adopt behavioral and sleep hygiene strategies to preserve technical performance before basketball practice and competitions.

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