



Original Article

Sleep deprivation leads to mood deficits in healthy adolescents

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ABSTRACT

Study objectives: The objectives of the study were to investigate the effects of 36 h of sleep deprivation on the discrete mood states of anger, depression, anxiety, confusion, fatigue, and vigour in healthy adolescents. **Method:** Twelve healthy adolescent good sleepers (six male), aged 14–18 years ($M = 16.17$, standard deviation (SD) = 0.83), spent three consecutive nights in the sleep laboratory of the Centre for Sleep Research: two baseline nights with 10-h sleep opportunities and one night of total sleep deprivation. Every 2 h during wakefulness, they completed the Profile of Mood States – Short Form. Mood across two baseline days was compared to mood at the same clock time (0900 h to 1900 h) following one night without sleep. **Results:** The subscales of depression, anger, confusion, anxiety, vigour, and fatigue were compared across days. All mood states significantly worsened following one night without sleep. Females showed a greater vulnerability to mood deficits following sleep loss, with greater depressed mood and anxiety following sleep deprivation only witnessed among female participants. While both males and females reported more confusion following sleep deprivation, the magnitude of this effect was greater for females. **Conclusions:** This study provides empirical support for the notion that sleep loss can causally affect mood states in healthy adolescents, with females having heightened vulnerability. Understanding the detrimental effects of insufficient sleep during adolescence is important, as it is a stage where sleep loss and mood dysregulation are highly prevalent. These findings escalate the importance of promoting sleep for the well-being of adolescents at this critical life phase.

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1. Introduction

Sleep deprivation has been linked to serious changes in mood states and their regulation [1]. While experimental studies have begun to elucidate the relationship between sleep and mood in adults, this relationship is under-researched in adolescents. Indeed, the lack of experimental research examining the impact of sleep on mood in adolescents has been identified as a critical gap in the literature [2]. To address this gap, the present study examines the effect of 36 h of sleep deprivation on the discrete mood states of depression, anxiety, anger, fatigue, vigour, and confusion in an adolescent sample.

Evidence for the relationship between sleep disorders and mood disorders is strong in adults and adolescents [3–6]. Indeed, sleep problems are one of the diagnostic criteria for major depressive disorder. However, it is unclear to what degree sleep loss can perturb mood in healthy adolescents. Establishing a causal link between sleep and mood in healthy populations would provide important support for the causal relationship between insufficient sleep and mood deficits, as well as highlighting the importance of preventative public health

strategies targeting sleep and well-being in this age group. As mood disorders are one of the leading causes of morbidity and mortality in adolescents [7], this is an important and timely area of research.

Previous work examining sleep deprivation in adults has elucidated a range of functional deficits associated with sleep, as well as potential biological mechanisms underpinning them. Adult research has shown mood deficits in response to both sleep deprivation and sleep restriction, including decreased vigour and increased confusion and fatigue [8,9]. Some studies have also found increased anger [1], anxiety [10,11], and depressed mood [12,13] in response to sleep loss; however, these mood states have not been shown to consistently worsen [8,9]. While vigour, confusion and fatigue worsen with moderate levels of sleep restriction, mood states, such as depressed mood, anger and anxiety, tend to worsen with more severe sleep restriction and, in particular, following total sleep deprivation [14]. This suggests a differential sensitivity to sleep loss between mood states. In addition, there may be a dose-dependent relationship between sleep loss and mood deficits, with greater sleep loss predicting greater mood deficits. This is consistent with the dose–response relationships between sleep duration and other functional outcomes [15]. As such, the present study utilises a condition of total sleep deprivation, rather than sleep restriction, to operationalise sleep loss in order to best establish a causal relationship between sleep loss and a range of discrete mood states.

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In addition, the sensitivity of different mood states to the same degree of sleep loss will be examined.

Despite many excellent studies in adults, there are several reasons why these findings cannot be generalised to adolescents. Adolescents differ from adults in terms of brain maturation, sleep homeostatic and circadian system function, and psychosocial milieu [16–18]. Adolescents are argued to have fewer resources to cope with the affective challenges they face because of their developmental stage [2]. Sleep has been shown to have a role in regulating emotional brain states, with the amygdala implicated in the processing of emotionally salient information [19]. In a functional magnetic resonance imaging (fMRI) study, Yoo and colleagues [19] found an amplified hyper-limbic response of the amygdala to aversive emotional stimuli under conditions of sleep deprivation and reduced functional connectivity between the amygdala and the medial prefrontal cortex (mPFC). The mPFC has an inhibitory function over the amygdala, meaning that heightened emotional reactivity related to amygdala function is not attenuated to the same degree by the mPFC during conditions of sleep loss. As the prefrontal cortex (PFC) is still developing in adolescents [2], mood deficits arising from sleep loss may be amplified.

While experimental research into the relationship between sleep and mood in adolescents is limited, several excellent studies have begun to explore this relationship in healthy populations [2,20–23]. Talbot and colleagues [2] restricted sleep to 6.5 h for the first night and 2 h for the second night, and then they compared mood (using the Positive Affect and Negative Affect Schedule for Children, or PANAS-C) to a rested condition in which participants slept between 7 and 8 h per night for two nights. This effect of sleep loss was investigated across early adolescents, mid-adolescents and adults. It was found that while adolescents reported less positive affect when sleep restricted compared to when rested, negative affect did not change. Adolescents also reported higher levels of anxiety following a catastrophising task and rated the likelihood of the catastrophes much higher when sleep deprived [2].

A study by Baum and colleagues [20] found changes to both positive and negative mood states following sleep loss. The authors conducted a home-based experimental sleep restriction protocol in a sample of 50 healthy adolescents aged 14–17 years. Participants completed one week of baseline sleep, followed by five nights of 6.5 h of time in bed (TIB) and five nights of 10 h of TIB in a counterbalanced order, with one weekend as a washout period in between conditions. Participants reported significantly more anxiety, anger, confusion and fatigue, and significantly less vigour on the Profile of Mood States during the sleep restriction period compared to the extended sleep week. Contrary to expectations, depressed mood did not change between conditions.

While these adolescent sleep restriction studies cast some doubt over the ability of sleep loss to perturb depressed mood, another study using a sleep extension paradigm found that more sleep resulted in less depressed mood [22]. Fifty-five adolescents were identified as having chronic sleep reduction, and they were randomised to either a sleep extension and sleep hygiene group or a control group. TIB was extended via earlier bedtimes over a 2-week period by 1 h and monitored actigraphically. At the end of the 2-week period, those in the sleep extension group obtained more sleep and reported decreased depressed mood on the Children's Depression Inventory. Unfortunately, other mood states were not assessed.

While these studies are invaluable in elucidating the possible causal relationships between sleep duration and mood, results have been inconsistent between studies and there are a number of methodological challenges yet to be addressed. For example, while Talbot and colleagues [2] brought participants into the laboratory for the second night of sleep restriction, the remainder of the sleep restriction/extension studies in adolescents utilised at-home protocols. These have the advantage of providing greater ecological

validity, but, as with any home-based sleep experiment, this comes at a possible loss to experimental control. Beebe et al. [24] acknowledged a potential for non-adherence to study protocols within home-based sleep restriction studies due to the lack of behavioural monitoring of participants. In one adolescent sleep restriction study, 15% of adolescent participants reported non-compliance with the protocol [25], and a number of participants disregarded prohibitions against drinking caffeine or napping. Relying on self-reported adherence to protocols means that participants may under-report their napping or caffeine use [24]. Some studies also allowed limited consumption of caffeine [20,22]. As caffeine can eliminate the mood and alertness deficits caused by sleep loss [26], this may have minimised or even ameliorated sleep-related mood deficits. Finally, there is uncertainty over the degree to which confounding factors known to affect both mood and sleep, such as physical activity [27] or exposure to bright light [28], are present.

To address these methodological concerns, the present study utilised a laboratory-based protocol. This study will add to our understanding of the effect of sleep loss on adolescent mood: (i) by establishing whether sleep loss can perturb a range of mood states in adolescents, including depressed mood; (ii) by establishing whether mood states differ in their sensitivity to sleep loss; and (iii) by establishing whether male and female adolescents differ in their mood response to sleep loss.

Participant mood following one night of total sleep deprivation was compared to that across two baseline days following 10-h sleep opportunities. It was hypothesised that there would be significantly increased depressed mood, anxiety, anger, fatigue and confusion and decreased energy following one night without sleep, when compared to two baseline periods when 10-h sleep opportunities are given. Based on findings from adults sleep deprivation studies [1,8–13], it is hypothesised that mood changes in response to sleep loss will be significantly greater for the discrete mood states of confusion, vigour and fatigue than for anger, anxiety, and depressed mood. Finally, there is some argument that mood deficits in response to sleep loss may be greater in females than males [29]. However, due to the lack of previous research addressing sex differences across the range of mood states, these analyses were exploratory.

2. Method

2.1. Participants

Participants included 12 adolescents (50% male) aged 14–18 years ($M = 16.17$, standard deviation (SD) = 0.83) who attended secondary schools in South Australia. Participants were physically and psychologically healthy, as determined by parent- and self-reported surveys. Participants who obtained <8 h of sleep per night, had average sleep onset latencies of >30 min per night, weekend bedtime delay of ≥ 2 h or who were extreme morning or evening chronotypes (total scores ≤ 22 or ≥ 44) were excluded from the study, as were participants who scored ≥ 16 on the Center for Epidemiologic Studies Depression Scale (CES-D) or received scores above 'mild' on any of the subscales of the Depression Anxiety and Stress Scale (DASS)-21. Participants did not use medication and they were free of any medical, psychological, and sleep disorders, as determined by parent and adolescent self-report questionnaires, a 7-day sleep diary and wrist actigraphy. Participants were either late or post-pubertal (Tanner stages 4 or 5), as measured by the Pubertal Development Scale [30], and they had normal or corrected-to-normal vision.

Ethics approval was granted by the University of South Australia Human Research Ethics Committee, and participants received an honorarium for their participation. Written, informed consent was obtained from each adolescent and a parent.

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