



## CLINICAL REVIEW

# Effects of sleep manipulation on cognitive functioning of adolescents: A systematic review



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## SUMMARY

Adolescents are considered to be at risk for deteriorated cognitive functioning due to insufficient sleep. This systematic review examined the effects of experimental sleep manipulation on adolescent cognitive functioning. Sleep manipulations consisted of total or partial sleep restriction, sleep extension, and sleep improvement. Only articles written in English, with participants' mean age between 10 and 19 y, using objective sleep measures and cognitive performance as outcomes were included. Based on these criteria 16 articles were included. The results showed that the sleep manipulations were successful. Partial sleep restriction had small or no effects on adolescent cognitive functioning. Sleep deprivation studies showed decrements in the psychomotor vigilance task as most consistent finding. Sleep extension and sleep improvement contributed to improvement of working memory. Sleep directly after learning improved memory consolidation. Due to the great diversity of tests and lack of coherent results, decisive conclusions could not be drawn about which domains in particular were influenced by sleep manipulation. Small number of participants, not accounting for the role of sleep quality, individual differences in sleep need, compensatory mechanisms in adolescent sleep and cognitive functioning, and the impurity problem of cognitive tests might explain the absence of more distinct results.

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## Introduction

Issues concerning sleep, cognitive functioning and learning capacity in adolescents have attracted much attention in recent years. Several reviews and meta-analyses have stressed associations of sleep quantity and quality with academic performance and effects of sleep loss on memory, attention, and more complex cognitive functions [1–4]. Due to the decreasing sleep time of adolescents worldwide and high prevalence of adolescent sleep problems [5–7], conclusive knowledge about the relation between adolescent sleep and cognitive functioning is highly needed.

Kopasz et al. [4] concluded in a review of 15 studies focusing on sleep and memory, that most studies support the hypothesis that sleep facilitates working memory as well as memory consolidation in children and adolescents, and that there is some evidence that decline of performance after sleep deprivation in abstract and complex tasks is stronger than in simple memory tasks. In a meta-

analysis, using a sample of 86 studies of 5–12 y, authors concluded that executive functioning and school performance are associated with sleep duration but that sleep is not associated with intelligence, sustained attention, or memory [1]. As indicated by another meta-analysis of 50 studies in children and adolescents, improved school performance is associated with increased sleep quality and sleep duration [3]. This analysis also suggests that sleepiness shows the strongest relation with school performance, followed by sleep quality and sleep duration. In a clinical review Curcio et al. [2] stated that what jeopardizes memory consolidation most is sleep loss or fragmentation.

The need for sleep is known to differ strongly between individuals and the debate on what constitutes 'optimal sleep' is still ongoing. General consensus on what amount is sufficient is mainly based on expert opinion and not on bias-free evidence [8]. Notwithstanding the discussion on adolescent sleep need, surveys of adolescent sleep duration report increased adolescent sleepiness and increased desire for more sleep [5–7]. In addition, adolescents with high chronic sleep reduction and short sleep duration showed impaired daytime functioning, including attention problems and worse school performance [9]. Taking these findings together, there are sufficient indications that sleep debt due to short sleep duration

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Abbreviations			
AVLT	auditory verbal learning task	RT	reaction time
AWM	arithmetic working memory task	SE	sleep efficiency
CBTI	cognitive behavioral therapy for insomnia	SOL	sleep onset latency
CPT	continuous performance test	SQ	sleep quality
CVWM	complex verbal working memory task	STS	spatial temporal span
DSS	digit symbol substitution	SVWM	simple verbal working memory task
FI	feature identification	TST	total sleep time
fMRI	functional magnetic resonance imaging	TTCT	Torrance tests of creative thinking
GDS	Gordon diagnostic system	VDS	visual digit span
MSL	memory search letters	WASO	wake after sleep onset
PVT	psychomotor vigilance test	WCST	Wisconsin card sorting test
		WM	working memory
		WWM	Williams word memory test

or worse sleep quality is prevalent among adolescents and that this generally results in impaired cognitive functioning.

There are several theories that explain deteriorated cognition by sleep debt. One theory concerning memory consolidation states that two processes take place during sleep: the consolidating process and resetting process. The information obtained during wakefulness is contained within the brain circuits and has to be consolidated to ensure future accessibility. One approach to model this is the synaptic-homeostasis hypothesis [10]. It suggests that because of a net increase of synaptic strength during wakefulness and to maintain synaptic homeostasis, synaptic downscaling occurs during slow-wave sleep. It solidifies the already strong memory traces while liquefying the weaker ones [11].

Another model explaining memory consolidation is the more active trace-reactivation hypothesis [12]. Transient memory traces (hippocampus based for declarative memory) are short-term and are thought to be copied to long-term memory (mainly neocortex based) via reactivation of memory traces during slow wave sleep [12,13]. Reactivation of a trace promotes gradual strengthening of the synaptic corticocortical connections and eventually results in a memory trace that is more stable and (mostly) independent of the hippocampus [14,15].

For attention processes, studies have found that after sleep deprivation the divergence between activation and deactivation of task positive and task negative networks becomes attenuated, which may influence attention-demanding tasks in adults [16,17]. These networks are associated with distinct neuronal structures in the brain, which undergo changes in both structure and connectivity during adolescent development [18] and interact with the consolidation and resetting processes. Sleep loss might therefore be especially perilous for adolescents as brain changes in adolescence interfere with these processes and can have lasting effects well into adulthood because of the neuronal malleability during adolescence [18].

Taken together, adolescents seem to be at risk for insufficient or bad sleep and may therefore be at risk for deteriorated cognitive functioning. The first aim of this systematic review is to examine the general effect of sleep manipulation on cognitive functioning of adolescents. We chose to examine the influence of both sleep deprivation (i.e., a prolonged period without sleep, also referred to as acute sleep restriction), sleep restriction (i.e., a prolonged period with a limited amount of sleep, also referred to as partial sleep deprivation) and sleep improvement, such as sleep extension and sleep treatment, to get insight into the possible differential effects of these two distinct forms of sleep manipulations on cognitive

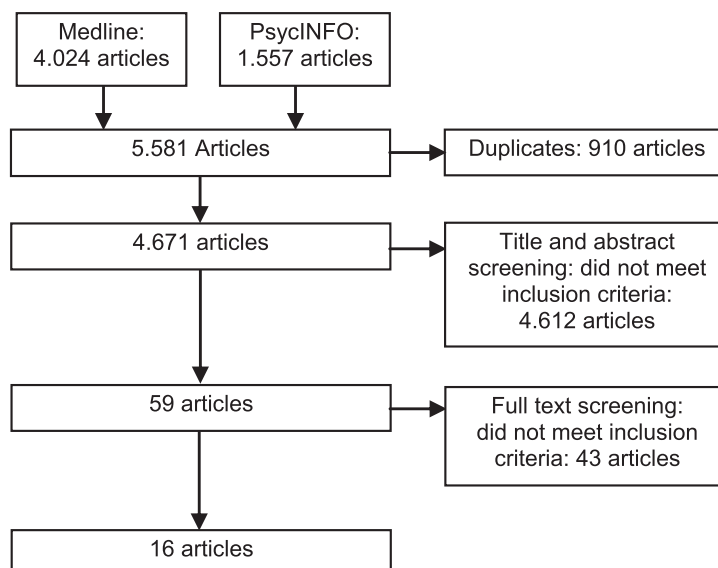


Fig. 1. Database search and article selection.

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