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The neurocognitive consequences of sleep restriction: A meta-analytic review

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ABSTRACT

The current meta-analytic review evaluated the effects of experimentally manipulated sleep restriction on neurocognitive functioning. Random-effects models were employed to estimate the overall effect size and the differential effect size across cognitive domains. Age, time of day, age-adjusted sleep deficit, cumulative days of restricted sleep, sleep latency, subjective sleepiness, and biological sex were examined as potential moderators of the effect. Based on a sample of 61 studies, from 71 different populations, findings revealed a significant negative effect of sleep restriction on cognitive processing across cognitive domains ($g = -0.383$, $p < 0.001$). This effect held for executive functioning ($g = -0.324$, $p < 0.001$), sustained attention ($g = -0.409$, $p < 0.001$), and long-term memory ($g = -0.192$, $p = 0.002$). There was insufficient evidence to detect an effect within the domains of attention, multitask, impulsive decision-making or intelligence. Age group, time of day, cumulative days of restricted sleep, sleep latency, subjective sleepiness, and biological sex were all significant moderators of the overall effect. In conclusion, the current meta-analysis is the first comprehensive review to provide evidence that short-term sleep restriction significantly impairs waking neurocognitive functioning.

1. Introduction

Sleep is an essential component of human health that is necessary for optimal functioning both mentally and physically. The neurocognitive deficits observed following sleep loss are experienced almost universally, and includes impairments in attentional processing, executive functioning, non-declarative and declarative memory, as well as emotional regulation and sensory perception (Durmer et al., 2005; Goel et al., 2009; Jones and Harrison, 2001; Walker, 2008). Such impairments are of special concern in that several everyday behaviours are dependent on optimal cognitive functioning, including the coordination activities of daily living (Best et al., 2015; Vaughan and Giovanello, 2010), emotional regulation (Gyurak et al., 2011; Ochsner et al., 2012), medication adherence (Hinkin et al., 2004; Insel et al., 2006), and dietary self-restraint (Hall, 2016).

For instance, attentional failures or lapses due to sleep loss are considered the primary causative factor underlying fatigue-specific transportation accidents (Philip et al., 2005; Philip and Akerstedt, 2006; Schwarz et al., 2016). Equivalent psychomotor impairments are observed during periods of acute sleep loss and alcohol intoxication (Roehrs et al., 2003; Williamson and Feyer, 2000), and the fatality rates of sleep-loss induced motor vehicle accidents are comparable to those caused by alcohol intoxication (Williamson and Feyer, 2000). Furthermore, neurocognitive impairments following sleep loss diminishes worker productivity and increases the likelihood of workplace errors and accidents (Lahti et al., 2011; Philip and Akerstedt, 2006). This has become of increasing concern within careers that require high-level cognitive performance at critical times, especially those that directly affect the life and safety of others (e.g., health care workers, pilots). It is evident that both acutely, and over time, suboptimal cognitive functioning due to sleep loss has the potential to degrade the health, safety, productivity, and wellbeing of the individual and population at whole.

The behavioural, cognitive and psychophysiological effects of total sleep deprivation (TSD) or extended wakefulness are well documented within the literature (Koslowsky and Babkoff, 1992; Lim and Dinges, 2010; Pilcher and Huffcutt, 1996). Specifically, acute TSD (i.e., 24–48 h) impairs neurocognitive functioning across almost all cognitive domains (Lim and Dinges, 2010). However, there is substantial variability in the sensitivity to sleep loss across cognitive domains, such that the largest performance decrements are observed for measures of sustained attention and working memory, whereas, comparatively, more complex tasks are affected to a lesser degree (Lim and Dinges, 2010). Nevertheless, TSD seldom occurs outside the context of a sleep laboratory and certain professions (e.g., medical personnel or emergency workers), thus, the ecological validity of such experimental protocols

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remains questionable. Conversely, the impact of sleep restriction or partial sleep deprivation on basic and complex cognitive processes has received substantially less attention within the literature; sleep restriction refers to sleep durations shortened below the age recommended range. Unlike TSD, restricted sleep is pervasive in most modern societies in that approximately 30 percent of adults (30–40%), school aged children (10–13 years old; 31%), and adolescents (26%) report sleep durations less than the age recommended amount (CDC, 2011; Chaput and Janssen, 2016; National Sleep Foundation, 2010).

Considering the prevalence of sleep restriction and the importance of optimal cognitive abilities in everyday consequential behaviours determining the impact of short-term sleep restriction on neurocognitive functioning is of the upmost importance. However, much of the current literature has centered around theoretical aspects of sleep restriction, such as sleep debt, sleep tendency and core versus optional sleep (Horne, 2011; Van Dongen et al., 2003b), or has focused on impact of chronic sleep restriction on cognitive performance (Reynolds and Banks, 2010). The latter is typically measured using self-report questionnaires, sleep diaries, and measures of activity such as actigraphy (Astill et al., 2012; Phillips, 2007). While such studies are important, complementary evidence from experimental studies is necessary to clearly establish directionality and causation. Although the current body of experimental evidence does indeed suggest that both acute and short-term cumulative sleep restriction (for up to approximately one week) exerts a deleterious effect on cognitive functioning (Banks and Dinges, 2007), the available studies have yielded conflicting results, and thus, no consensus regarding the impact of sleep restriction on cognition has emerged within the literature.

To date, no fully comprehensive meta-analysis has been conducted to quantify the magnitude of the effect of short-term experimentally manipulated sleep restriction on neurocognitive functioning across cognitive domains and age groups. There are several reasons why the current meta-analysis is needed. First, much of what is known about the effects of sleep loss on neurocognitive functioning has been derived from TSD experimental studies. As TSD represents the extreme end of sleep loss and occurs infrequently outside the context of the sleep laboratory it is currently unclear whether comparable effects are observed within a more naturalistic sleep loss paradigm. Second, the prevalent nature of sleep restriction and importance of optimal cognitive abilities in everyday behaviours warrants investigation into extent in which restricted sleep impairs neurocognitive functioning. Finally, although two prior meta-analytic reviews have demonstrated that sleep restriction has a small, but significant, negative impact on complex cognition (Wickens et al., 2015) and attention and hyperactivity measures in adolescents (Lundahl et al., 2015), these past reviews had several limitations that remain to be addressed, most notably the specificity of focus within sub populations (i.e., adolescents) and/or cognitive domains (i.e. attention and complex tasks). Moreover, the cognitive categories used in past reviews were relatively coarse in that there was no distinction between the different aspects of attention nor between the cognitive processes underlying complex cognition (e.g., executive functioning).

The purpose of current meta-analytic review was to quantify the effects of short-term experimentally manipulated sleep restriction on explicit or conscious neurocognitive functioning across both cognitive domains and age groups [children (3–5 years), school-aged children (6–13 years), adolescents (14–17 years), young adults (18–30), adults (31–59), older adults (60+)]. Investigation into the differential impact of sleep restriction across the lifespan is of importance as both the prevalence of sleep restriction and tolerance to the effects may differ depending on age (Basner et al., 2014; Duffy et al., 2009; Stenuit and Kerkhofs, 2008, 2005). The current review also examined the aggregated and differential effect of reaction time, accuracy, and cognitive domain-specific performance variables for both the overall effect and within each relevant domain. There is insufficient evidence to suggest that reaction time, accuracy, and cognitive domain-specific performance variables are uniformly affected by restricted sleep, and thus, dissipating these variables may provide insight into the mechanisms underlying sleep restriction-induced impairments in neurocognitive functioning.

2. Methods

2.1. Literature search and study selection

A search of PubMed, Scopus, Web of Science and PsychInfo was conducted in November 2016 using the following search terms: *sleep restriction, sleep manipulation, sleep fragmentation, partial sleep deprivation, or sleep loss* combined with *executive function, executive control, cognition, cognitive, memory, inhibitory control, response inhibition, set shifting, task shifting, task switching, mental flexibility, decision making, attentional control, attention, verbal fluency, psychomotor vigilance, intelligence, recall, response time, reaction time, delay discounting, event related potential, or ERP*. The search terms were determined *a priori*. In addition, relevant database-specific terms (e.g., MESH terms) were used. Results were limited to articles published in English only, and the following terms were used to exclude articles with animal or clinical populations: *cognitive behavioural therapy, cognitive behaviour therapy, CBT, mice, mouse, rat, monkey, rodent, cat, drosophila, insomnia, narcolepsy, depression, epilep*, sleep apnea, sleep apnoea, sleep inertia, mild cognitive impairment, or sleep quality*. The exclusion terms were determined *post-hoc*. Reference lists of relevant articles and pertinent reviews were hand searched for additional articles.

2.2. Inclusion/Exclusion criteria

An overview of the study selection process is outlined in Fig. 1. Two authors (C.L. and A.S.) conducted the initial abstract review independently. Suitable studies were selected for inclusion according the following criteria; (1) healthy human study population; (2) experimental manipulation of the sleep restriction protocol; (3) comparison to a normal sleep baseline; (4) at least one behavioural measure of explicit or conscious cognitive functioning. The specific cognitive domains included in this review are outlined below. Included studies were not restricted by publication date, age group, study design, or the duration of the sleep restriction manipulation. Studies that did not experimentally manipulate the sleep restriction protocol, or those that did not compare the effects of sleep restriction to a normal sleep baseline (control) measure were excluded. In addition, studies that examined the impact of sleep restriction on emotional processing or valence ratings, and/or implicit and procedural memory were excluded from the current review. If multiple studies were published using the same participants, to prevent homogeneity inflation due to correlated data, only the study with the largest sample was included in the analyses. If the results from different cognitive tasks within the same study were reported in more than one publication ($k = 1$) the cognitive task data were collated into a single study for all analyses (Higgins and Green, 2011). This approach ensures the use of all available data while maintaining the notion of population per study (Higgins and Green, 2011).

2.3. Study quality

Two authors (C.L and A.S.) independently assessed risk of bias, and extracted information on study design and participant representativeness. The risk of bias for individual studies was assessed using the Cochrane risk of bias assessment tool; ratings of low, high, and unclear were assigned to each dimension based on the criteria outlined by the Cochrane Collaboration (Higgins and Green, 2011). However, blinding of participants was not considered for quality assessment, as it would have impossible to blind participants to their allocated sleep conditions. In addition, individual studies were assigned a rating of yes, no, and unclear on the following dimensions: (1) population representativeness;