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Review Article

The effects of sleep loss on capacity and effort

Mindy Engle-Friedman

Baruch College, City University of New York, New York, NY, USA

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ABSTRACT

Sleep loss appears to affect the capacity for performance and access to energetic resources. This paper reviews research examining the physical substrates referred to as resource capacity, the role of sleep in protecting that capacity and the reaction of the system as it attempts to respond with effort to overcome the limitations on capacity caused by sleep loss. Effort is the extent to which an organism will exert itself beyond basic levels of functioning or attempt alternative strategies to maintain performance. The purpose of this review is to bring together research across sleep disciplines to clarify the substrates that constitute and influence capacity for performance, consider how the loss of sleep influences access to those resources, examine cortical, physiological, perceptual, behavioral and subjective effort responses and consider how these responses reflect a system reacting to changes in the resource environment. When sleep deprived, the ability to perform tasks that require additional energy is impaired and the ability of the system to overcome the deficiencies caused by sleep loss is limited. Taking on tasks that require effort including school work, meal preparation, pulling off the road to nap when driving drowsy appear to be more challenging during sleep loss. Sleep loss impacts the effort-related choices we make and those choices may influence our health and safety.

1. Definition of effort

Recent research has begun to clarify how sleep loss affects capacity and access to energetic resources. Investigators across the sub-fields of sleep research have also identified cortical, physiological, perceptual, behavioral and subjective effort responses that reflect a system attempting to function normally in a resource environment changed by sleep loss. This research enhances our understanding of the physical substrates referred to as resource capacity, identifies how sleep protects that capacity and illuminates the impact of sleep loss on the normal utilization of those resources.

According to Kahneman [50] the extent to which a person can attend to or engage in activity is limited by a physiological maximal processing capacity. Information processing of differing types requires varying levels of attention and engagement and each makes unique demands on the limited processing capacity from moment to moment. Effort is an attempt by the system to meet the needs of the organism. When the system meets the organism's basic information processing needs it is operating under automatic control and though effort is needed, it is low and strain is not detected by the person. Increased time on task, time pressure and off-task distractions require resources in excess of that needed

E-mail address: mindy.engle-friedman@baruch.cuny.edu

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for basic information processing. When this happens, the person attempts to maintain performance by applying additional effort and further engaging the system. If resources are depleted or unavailable the person becomes fatigued or exhausted, reduces engagement and eventually gives up [1].

Speed of performance [75], work rates ([17,24,98] [87]), number of problems attempted [4,13,41]; Webb and Levy, 1984) and choice of tasks of various degrees of difficulty [7,79] have been used to determine performance effort. The subjective experience of effort is the sense of perceived exertion when performing beyond the fulfillment of basic task requirements [55] and the available energetic resources.

This review [6,96] will explore our current understanding of capacity, particularly with a focus on energy, how sleep loss affects energy resources and how effort is applied to maintain performance. In particular it will review research contributing to our understanding of capacity, how energy availability is affected by sleep loss, the cortical and physiological outcomes that influence capacity, the perceptual changes in task difficulty in response to sleep loss, how compensatory behavior has been applied in response to the limitations imposed by sleep loss, and the subjective experience of effort under sleep loss conditions.

2. Historical background—Capacity, sleep loss and effort

The impact of sleep loss on the availability of resources and the application of effort to accomplish goals has been of interest since the early days of sleep research. Researchers studying sleep deprivation approached the topic in three primary ways. They considered how performance was maintained through compensatory effort and evaluated the subjective reports of the expenditure of effort under conditions of sleep loss. The absence of performance deficits following sleep loss was considered to result from the application of compensatory effort [25,34,76] and assumed that without additional effort directed toward alert and focused engagement, poor performance would result. In one early study, the author and his wife, the only participants in the study, reported that they had to apply greater effort to perform efficiently on days following sleep loss. They proposed that voluntary 'effort' compensated for the subjective experience of impairment and surmised that expended effort increased in proportion to the amount of sleep lost. To prevent impairment on mental arithmetic, a person having slept 6 h instead of 8 would have to apply 25% greater "energy expenditure" [57].

3. Theoretical and applied value of examining capacity, sleep loss and effort

3.1. *Theoretical value*

Research in the area of sleep and effort has both theoretical and applied value. Such research enhances our understanding of the substrates that constitute and influence capacity for performance and clarifies the role of sleep in protecting those resources. Experimental work in this area helps also helps us consider the attempted compensatory responses and the interaction between genetic, cortical, physiological, perceptual and behavioral systems when sleep loss impacts the system.

3.2. *Applied value*

Adults and children delay sleep and curtail the sleep period deliberately by extending time at work, completing homework assignments and participating in computer and web-based activities [62,63]. Others lose sleep due to insomnia, apnea or medical conditions that interfere with sleep. Approximately 70% of US adults feel they get less sleep than they need and sleep an average of 6.5 h during the week but feel they need 7 h to function well (Sleep in America Poll, 2014). Adolescents (10–17 years) need 9 h of sleep [15] but over half of the 15–17 year olds, almost a third of the 12–14 year olds and 8% of the 6–11 year olds sleep 7 h or less (Sleep in America Poll, 2013). Overall, adults and children sleep less than they need and that loss of sleep influences the choices they make. When adolescent athletes, for example, had less sleep they had poorer mood and considered their drills in sports practice to be more difficult, and when they had more frequent awakenings they avoided the most challenging exercises [30]. Children and adolescents who have insufficient sleep may experience classroom work as more difficult than they would if they had sufficient sleep. Enhanced perceptions of difficulty may lead to decisions to work on easier tasks. Such perceptions and choices could influence students' educational growth.

Health-related choices made by adults in a preliminary study, were also affected by previous nights' sleep. Adults reporting problems with sleep latency, awakenings and total sleep time in comparison to those with no sleep problems were more likely to eat restaurant-prepared or fast-food rather than food made at home [27,29]. Meals prepared out of the home may require less effort but may be less healthful than meals prepared at home. Over time, persons with restricted sleep may have weight or health problems related to the reduced effort they expended by choosing to purchase rather than prepare their meals.

A dangerous outcome of sleep loss is the impact it has on a driver's ability to stay awake. The risk of car crashes with injuries has been associated with the loss of sleep [19]. In comparison to people who sleep eight or more hours, those who sleep 6 to 7 h are twice as likely, and those who sleep less than 5 h are four to five times as likely to be involved in a crash [91]. Many drivers drive when they are tired and 11% reported having nodded off or fallen asleep while driving within the past 12 months [93]. The drivers report having been aware of being tired before the crash. Their attempts to compensate for the fatigue was insufficient to overcome the limitations imposed by sleep loss and they did not expend the effort needed to locate a place to nap and delay arrival at their destinations.

Research exploring the effects of sleep loss on the capacity to perform, perception of task difficulty and willingness to engage may lead to a greater understanding of the limits caused by insufficient sleep on the performance of activities