Sleep's Role in Effortful Performance and Sociability

Mindy Engle-Friedman and Steven G. Young

How we perform at home, at work, with our families and with others is a function of many factors. Often the role of sleep in those activities is overlooked. Although people may anecdotally recognize that poor sleep makes them ill-tempered or easily distracted, the full scope of impairment associated with lack of sleep is rarely appreciated. Yet, as a growing literature shows, sleep quality and duration affect the ability to engage in effortful cognitive and behavioral tasks, including navigating and understanding social interactions. In addition, since sleep need varies, individual differences also impact the effect sleep or sleep loss has on our decisions to expend energy and on what activities those critical resources will be used. In the present chapter, we provide an overview of research exploring the role of sleep in the availability and use of psychological resources and energy, both in performance domains (e.g., academic and workplace) and in social behavior. Additionally, we discuss open questions and future research directions with an emphasis on gaps in our knowledge of how sleep impacts human performance and sociability.

Sleep, Resources, and Effort

The ability to perform to capacity across many domains of daily life seems to be determined, at least in part, by how much sleep we have accumulated over the course of the night, the continuous and uninterrupted nature of that sleep, and longer-term cumulative sleep debt. This chapter will review the role of sleep in performance

M. Engle-Friedman (✉)
Department of Psychology, Ombuds, Baruch College Task Force on Sustainability, Baruch College, New York, NY, USA
e-mail: mindy.engle-friedman@baruch.cuny.edu

S. G. Young
Baruch College and The Graduate Center, University of New York, New York, NY, USA

Z. Križan (ed.), *Sleep, Personality, and Social Behavior*,
https://doi.org/10.1007/978-3-030-30628-1_5

capacity, how humans attempt to compensate for the challenges to capacity caused by sleep loss, the energetic costs of social behavior, how sleep loss influences that behavior, and the possible physical substrates referred to as resource capacity.

When an organism applies exertion beyond basic functioning or chooses alternative strategies to maintain acceptable levels of performance, that exertion is referred to as effort. This chapter will provide an overview of research across disciplines that seeks to identify how sleep affects the capacity for performance, access to resources necessary for performance, and behavioral and subjective effort responses to the absence of sleep. One area of great behavioral importance is social behavior. This chapter will highlight the role of sleep on observable social behavior, with an emphasis on social actions that typically require effort and explicit cognition. Lastly, the cortical, physiological and neurological reactive to sleep loss that influence behavioral sequelae will be considered.

Effort

Before understanding how sleep quantity and quality moderate effort and performance, we should first define *effort*, a concept that has a long history in psychology. For example, early discussions centered around whether effort (conceptualized as attending to and thinking about a stimulus) was a purely "intellectual" endeavor detached from physical limitations, or instead an embodied process subject to fatigue and resource availability (Dewey, 1897). The intervening years have settled this particular debate and contemporary examinations of effort define the term as the challenge an organism experiences in allocating attention to a task and engagement in activity that is bounded by physiologically-based processing capacity (Kahneman, 1973). Each activity or task we engage in has unique demands of attention and information processing. Each organism has a limited processing capacity that varies from moment to moment depending on the state it is in (Hockey, 1997; e.g., Todd, Hertwig, & Hoffrage, 2015). The organism or system operates under automatic control when its basic information processing needs are met, the demands on the system are low, and strain is not detected. In these benign situations, effort is expended but the resources needed are matched by those available. However, as situational variables like time pressure, task duration, and non-task distractions place demands on the organism, additional resources are needed for basic information processing and to maintain performance (see Foster & Lavie, 2009; Lavie, 2005). In other words, maintaining speed on a task, persisting for a long time on task, or fighting to maintain attention in the face of competing demands all increase the effort needed to perform a task. If resources are unavailable or if they become depleted, the person will become fatigued or exhausted, reduce task engagement and performance quality, and eventually abandon task-related action (Ackerman, 2011). Interesting, highly stimulating and competitive tasks that offer feedback can maintain engagement for at least a short period of time (see Horne & Pettitt, 1985; Wallerstein, 1954; Wilkinson, 1961).

The extent to which effort is allocated to task demands exists both as a subjective state and a physically grounded and observable variable. Subjective effort is the sense of having exerted oneself beyond the basic demands of the task and can be reported consciously during or after task performance (Knicker, Renshaw, Oldham, Simeon, & Cairns, 2011). On the other hand, objective behavioral effort is determined using observable and measurable outcomes, including speed of performance, work rates, number of problems attempted and choice of tasks of various degrees of difficulty.

Sleep Loss Leads to Increases in Subjective Effort

Sleep loss both triggers a change in capacity to perform at optimal levels and as well as the perception of increased task difficulty. The brain seems to determine the resources needed to complete the task, assesses whether those resources are accessible, judges the task in relation to available resources and decides whether resources should be used or conserved for higher priority tasks. While the comparison of task demands and resource availability are likely made at the cortical level, the subjective awareness of some elements of the process are available including the extent to which the task feels challenging and the person's interested in engaging in it. In one study, even 1 day of sleep loss caused college students to rate a reading task as significantly more difficult and requiring more time (i.e., more effortful) when compared with students who had their typical complement of sleep (Engle-Friedman, Hayrapetyan, Orodel, & Loshak, 2018). Following 2 days of total sleep loss and the requirement to work continuously, participants perceived that the work load had increased and reduced their walking pace (Rodgers et al., 1995) and physically fit athletes who experienced fatigue judged that the task had become more difficult (Proffitt, 2006). Adolescent athletes who reported that their previous night's sleep was less than what they needed to feel rested reported poorer mood and reported that their sports practice drills were more difficult, and the athletes with the most frequent awakenings preferred the simplest practice exercises (Engle-Friedman, Palencar, & Riela, 2010). Collectively, these examples illustrate that sleep deficits produce changes in subjective effort, including estimates of how long a task takes, how much work the task requires, and task difficulty. Additionally, these increased estimates of task difficulty have motivational and affective consequences.

Sleep Loss Leads to Reductions in Objectively-Measured Effort

Laboratory-based objective indications of decreased effort following sleep loss include reductions in work rates (e.g. Chmiel, Totterdell, & Folkard, 1995) and the number of solutions participants have attempted in response to experimenter-generated problems (e.g. Blagrove, Alexander, & Horne, 1995). The choices people make about alternatives requiring different levels of effort also change following sleep loss. When participants can select tasks from those of varying difficulty levels they choose simpler math addition problems (Engle-Friedman et al., 2003), non-academic tasks that require little effort (Engle-Friedman & Riela, 2004) and only the high priority tasks when offered low and high priority choices (Hockey, Wastell, & Sauer, 1998). Time spent reading for school, dressing neatly and dressing fashionably is reduced following a night of lost sleep (Engle-Friedman et al., 2003; Engle-Friedman & Riela, 2004) and participants are more likely not to follow the task rules, possibly taking an expeditious task completion strategy thereby limiting expended energy and effort (Nilsson et al., 2005).

The use of heuristics or mental short-cuts also increases with sleep loss. In comparison to students who experienced their typical sleep, those with no sleep were more likely to skip instructions. They were also more likely to use the what-is-beautiful-is-good heuristic by rating as poor quality a consumer item with a favorable written review but which was physically less attractive. Those with the greatest reported fatigue were most likely to rate positively the physically attractive consumer item and negatively rate the unattractive consumer item despite the content of the consumer review (Engle-Friedman et al., 2018).

After Sleep Loss Effort Is Maintained for Shorter Periods of Time

Effort can be maintained during sleep loss if the circumstances are right. Task elements that can help maintain effort are incentives and feedback (e.g. Horne & Pettitt, 1985; Steyvers & Gaillard, 1993), the participant's interest in the task and assessment of the task's relevance. Games that involve sensory stimulation, competition or motoric output or those that involve electric shock provide further examples of contexts that lead to persistence even in the face of sleep deprivation. When the sleep deprived person is aware that the last session of the assessment is approaching, often following the study's most prolonged sleep deprivation period, an increase in task performance and effort is commonly observed (Angus & Heslegrave, 1985).

The performance facilitation by these factors, however, is limited. Feedback, for example, shortened reaction time but did not improve accuracy in one study (Steyvers, 1987) and in another study, incentives could not maintain baseline performance past 36 hours of sleep deprivation (Horne & Pettitt, 1985). These effects illustrate that eventually the energetic cost of sleep deprivation will overcome situational factors that encourage persistence.

Theoretical and Applied Value of the Study of Sleep Loss, Effort and Performance

Investigations of sleep and effort provides both theoretical and applied benefits. Understanding of the substrates of capacity for performance and how sleep impacts those substrates can help us protect resources vital to our optimal functioning. It also offers both micro and macro assessments of how effort is effected and performance is impacted when sleep is lost. Experimental work in this field helps identify the compensatory responses and the interaction between various behavioral responses, as well as the interactions of genetic, cortical, neurological, physiological and perceptual systems under sleep loss conditions.

Loss of Sleep Is a Ubiquitous Problem

Nearly 70% of adults in the US believe they sleep fewer hours than they need averaging a weekly 6.5 hours but feel they need 7 hours to function optimally (National Sleep Foundation, 2014). Over 50% of adolescents 15–17 years old, nearly a third of those 12–14 years old and 8% of those 6–11 years old, sleep 7 or fewer hours per night (National Sleep Foundation, 2013) even though adolescents (10–17 years) have been found to require at least 9 hours of sleep for best performance (Carskadon & Acebo, 2002). Children and adults engage in computer and internet activities, complete homework and finish workplace-based projects at night curtailing total sleep time (National Sleep Foundation, 2013, 2014). Sleep apnea and medical conditions prevent and interrupt sleep leading to insufficient sleep which affects next day performance. All told, getting insufficient sleep is a commonplace problem across the life-span. This has implications for daily functioning and wellbeing, including affecting day-to-day judgment and decision making, social interactions, and self-regulation.

Daily Choices

Wide-ranging surveys indicate that children and adults sleep less than their optimal amount. It also appears sleep loss impacts their decision-making. Following less sleep than preferred, for example, serious adolescent athletes reported poorer mood and considered their sports practice drills to be more challenging, and with more frequent awakenings these athletes avoided the most difficult practice exercises (Engle-Friedman et al., 2010). The choices students make in the classroom, during homework completion, and in social settings when they have had less sleep than they need has not yet been thoroughly investigated. When sleep loss affects decision-making and choice behavior in settings where important learning and growth opportunities are present, students' educational development may be disadvantaged. For example, lab research finds sleep deprivation decreases verbal learning in young participants (e.g., Drummond et al., 2000). Relatedly, the transfer of learned information to long-term memory is impaired following sleep loss (Gais, Lucas, & Born, 2006). Meta-analytic evidence finds similar results across academic domains and in naturalistic contexts (Dewald, Meijer, Oort, Kerkhof, & Bögels, 2010).

The quality of one's previous night's sleep also affects next-day health-related choices. Adults who reported trouble with falling asleep, frequent awakenings and total sleep time were more likely to eat fast-foods or to eat at restaurants rather than preparing meals at home (Engle-Friedman et al., 2010). The purchase of prepared meals away from home may require less effort but they also be less nutritious than meals prepared at home. Sleep loss experienced by those with sleep problems may result in the added and underappreciated impact on the effort involved in meal preparation. The consumption of fast food including foods high in fats and carbohydrates following sleep loss is likely a result of an interaction between systems responsible for effort, temperature regulation and energy metabolism.

Even a few hours of lost sleep causes core body temperature to drop in humans (Shaw, 2005) and we attempt to reduce feeling cold by increasing the ambient heat by adding clothing (Horne, 1998). In the absence of sleep, humans use one third more energy than they would if they were sleeping and conserving that energy (Jung et al., 2011). The inability to retain body heat was originally observed in rats who expend more energy than normal and increase their food consumption when sleep deprived (Rechtschaffen & Bergmann, 2002).

Sleep affects the ability to store energy and to make it available. Energy regulation through food intake is affected by the hormone gherlin, which stimulates appetite, and by the hormone leptin, which inhibits the desire to eat (Spiegel, Leproult, & Van Cauter, 2005). After two nights of sleep limited to 4 hours in bed gherlin is increased by 28% and leptin is decreased by 18%, with appetites directed toward high calorie foods (Spiegel, Tasali, Penev, & Van Cauter, 2004). Energy is made more available with sleep loss and less is stored. When sleep is restricted for 5 days, insulin, the hormone responsible for energy storage, is released 40% more slowly and the acute insulin response to glucose is reduced by 30% (Spiegel, Leproult, & Van Cauter, 1999). Sleep loss appears to create a physiological cascade in response to the detection of energy depletion. Instead of storing energy, energy becomes easily accessible and hormones signal that energy stores need immediate replacement. Therefore, the desire to engage in less effortful food preparation is paired with reduced energy stores, a desire to eat high calorie foods and a fast food market that provides easy access to such offerings.

Sleep loss plays a critical role in driving performance and accident likelihood. The risk of vehicular accidents that involve injuries has been related to sleep loss (Connor et al., 2002). In comparison with those who get eight or more hours of sleep, on average those who sleep 6–7 hours are two times as likely, and those sleeping fewer than 5 hours are 4–5 times more likely to experience a vehicular accident (Stutts, Wilkins, & Vaughn, 1999). Though drivers often report feeling tired when they drive long distances they continue driving anyway. Over 1 in 10 report having nodded off or having fallen asleep while driving a car in the last year. Moreover, strategies used to overcome the fatigue caused by sleep loss were insufficient to maintain maximally safe and effective driving performance. In addition, drivers do not expend the needed effort involved in changing course, locating a place to sleep and delaying arrival at their destination (Tefft, 2010).

Societal Impacts

While sleep loss research has typically focused on the individual within the controlled laboratory setting, the impacts of sleep loss may have broad societal costs. The accumulated effort-related decrements in performance by many functioning in a state of fatigue and sleepiness are likely underappreciated. In the healthcare domain, research has examined how sleep deficits can impact decision making. A review of the prescribing of antibiotics by 204 primary care physicians that met the "sometimes indicated" and "never indicated" criteria progressively increased over their 3-hour work sessions (Linder et al., 2014). In an examination of 4000 health care workers studied over the course of the work shift, an 8% decline in the frequency of hand washing was reported (Dai, Milkman, Hofman, & Staats, 2015). In a study of parole decisions made by judges, the more effort-demanding favorable verdicts were made at a rate of 65% at the start of the court session to 0% at the end (Danziger, Levav, & Avnaim-Pesso, 2011). And most profoundly, fatigued persons have shorter reaction times in a shooting simulation of Black armed suspect depictions, supporting the critical concern that fatigue can cause a reliance on racial bias and stereotypes (Ma et al., 2013).

Social Cognition and Behavior Following Sleep Disruption

The consequences of inadequate sleep extend to interpersonal domains, including the processing of social information and behavior in social contexts. As one example, sleep deprivation is linked to decreased sensitivity to facial expressions of emotion. A wealth of recent research has found that sleep loss decreases detection accuracy only for relatively subtle emotion displays that were created by blending neutral faces with an expressive version of the same target (e.g., Cote et al., 2014; Huck et al., 2008). A recent reanalysis of these data found that the impact of sleep deprivation was most notable for affiliative facial expression like happiness and sadness, with identification of these expressions becoming less accurate following sleeplessness, while recognition of threatening expressions like anger was unaffected after a night of sleep loss (Killgore, Balkin, Yarnell, & Capaldi, 2017).

Moreover, related work suggests that the perception of threating expressions like anger may even be heightened in participants deprived of sleep (Goldstein-Peikarskli, et al., 2015, but see Cote et al., 2014).

These findings have considerable implications for social functioning. Emotional displays convey vital social information about the expresser's current internal state and likely behaviors (e.g., smiling signals happiness and beneficent approach intentions while snarling signals anger and harmful approach intentions e.g., Parkinson, 2005). Misidentifying these signals has obvious social consequences; in the case of sleeplessness, opportunities to form positive interpersonal bonds or offer aid to those in need will be missed if expressions of happiness and sadness are not accurately decoded. Moreover, a tendency to overestimate threat from faces will lead to avoidance of benign people. More generally, poor emotion identification contributes to awkward and disfluent social interactions (e.g., Gray, Mendes, Denny-Brown, 2008), suggesting an increase in dissatisfying and uncomfortable social interactions following sleep loss (see also Sundelin and Holding, chapter "Sleep and Social Impressions", this volume).

Consistent with this notion, relative to rested controls, participants denied sleep demonstrate reduced empathic concern for others. This effect manifests in both self-report emotional distress and experienced arousal in response to observing images of strangers in emotionally provocative situations (e.g., grieving at a funeral; Guadangi, Burles, Fererra, & Iaria, 2014). Thus, decreased emotional responsivity that accompanies poor sleep extends beyond poorly identifying emotional expressions but affects interpersonal processes like helping intentions and empathic arousal (see Goldschmeid, chapter "How Sleep Shapes Emotion Regulation", this volume, for further discussion about the role of sleep in emotions).

Perhaps more directly, changes in sociability have been observed to follow periods of sleep deprivation. The ability to express oneself to others after sleep loss is impaired. After no sleep, the ability to generate words, to use the correct voice intonation and to flexibly move between semantic categories is reduced with increases in monotonic or flattened voices (Harrison & Horne, 1997). This impairment in communication could hinder effective relationship maintenance and building. An early controlled experiment by Laties (1961) withheld sleep for a 37-hour period in randomly selected male participants, who worked on both group and individual tasks. Although task performance was unaffected comparing rested to sleep deprived participants, those in the deprivation condition reported general negative social interactions, increased verbal aggression and decreased mood. A recent review verifies this link between sleep deprivation and interpersonal aggression in numerous contexts and across studies employing various research methodologies (Kamphuis, Meerlo, Koolhaas, & Lancel, 2012; Krizan & Herlache, 2016).

Other intragroup processes are affected by sleep loss as well. For example, social loafing involves poorer performance when one works in a group setting when compared with individually performed tasks (Latane, Williams, & Harkins, 1979). Sleep deprived participants who knew that the group score and not their own individual score would be evaluated, completed fewer trials and had increased incorrect responses when compared with those who were sleep deprived and worked individually (Hoeksema-van Orden, Gaillard, & Buunk, 1998). These findings suggest that a reduction in effort will occur when a sleep deprived person believes that other group members will make equal or greater contributions to the outcome, so they are free to exert a lower level of effort – one that is most comfortable for them at that time.

These negative social-behavioral outcomes extend to close relationships as well. For instance, in one large scale naturalistic demonstration using daily sampling methods to understand how sleep affects romantic couples, poor sleep was found to predict negative mood in both the sleeper and their partner the next day (Moturu, Khayal, Aharony, Pan, & Pentland, 2011) and is a contributing factor in relationship strife (e.g., decreased ability to resolve conflicts and empathize with a partner, e.g., Gordon & Chen, 2014) demonstrating both direct and diffuse impacts of sleep loss in social relationships.

Sleep and Self-Regulation

In a different social domain, sleep deprivation is associated with decreased regulatory ability and impairments in effortful social cognitive tasks (Barnes, Schaubroeck, Huth, & Ghumman, 2011, see Hisler and Križan, chapter "Dynamics between Sleep and Self-Control", this volume for review). For example, sleepy participants engage in more stereotyping than well-rested controls (Ghumman & Barnes, 2013). Notably, stereotype activation is well-known to occur automatically, whereas making more individuated and unbiased assessments require considerable cognitive effort and resource availability (e.g., Bargh & Chartrand, 1999; Devine, 1989; Moskowitz, 2010). Therefore, evidence suggests that sleeplessness compromises the ability to effortfully control activated stereotypes. Other forms of self-regulation and control are disrupted as a consequence of sleep deprivation, including regulating one's own emotions and inhibiting impulsive behaviors (for a review see Palmer & Alfano, 2017). This follows from the impacts of sleep deficiencies on effortful processing and cognitive control more generally. Just as sleep impairs performance on tasks that require resources and energy, this is true of controlled and regulating one's own emotional experiences. On a neurocognitive level, these regulatory failures are consistent with sleep deprivation decreasing activation in the prefrontal cortex (i.e., the brain region responsible for controlled cognition and self-regulation; e.g., Durmer & Dinges, 2005).

Together, this work illustrates the social cognitive and interpersonal costs of sleep deprivation. Insufficient sleep can impact emotional processes, including expression identification, empathy, interpersonal behavior, and control of one's own emotions. Moreover, it can also impact intergroup relations by leading to increased stereotyping. These diffuse effects cut across many areas of social psychology and suggest that fatigue and sleep deprivation play a perhaps underappreciated role in social cognition and behavior.

Challenging Methodological Barriers

The greatest methodological barrier to appreciating the impact of sleep loss on effort is that effort is most often assessed through self-report. Sleepers and non-sleepers are asked to identify the intensity of the effort they exerted on a previous task on Likert scales. In some studies, computerized visual analogue scales with effort represented on a 100 mm line are presented, while in other studies participants choose numbers ranging from 1 to 10 on symmetric agree-disagree scales. What effort feels like and how one assesses one's own effort exertion is complicated by the fact that measures of subjective effort are not consistent between studies. Depending on the lab and the study within an individual lab, participants have been directed to provide their subjective experience of their effort during the task (e.g. Nilsson et al., 2005; Odle-Dusseau, Bradley, & Pilcher, 2010), the effort required by the task (Drummond, Meloy, Yanagi, Orff, & Brown, 2005), the demanding nature of the task (Hockey et al., 1998), their effort involved in maintaining primary work goals or performance (Hockey & Sauer, 1996; Hockey et al., 1998), their concentration on the task (Drummond et al., 2005; Hockey et al., 1998), task difficulty (Drummond et al., 2000, 2005), their motivation to perform the task well (Drummond et al., 2005; Odle-Dusseau et al., 2010), and the difficulty of the upcoming task and their anticipated success on the task (Pilcher & Walters, 1997).

Refining the Measurement of Subjective Effort

The subjective experience of effort is a conundrum due to the variability in methods of measurement, the various physical dimensions tapped by those assessment methods, and individual differences in the interpretation of and response to the questions asked. Respondents are not given reference points or physical guidelines to use when making these determinations and reports of effort exerted (whether in the fully rested or in the sleep deprived state) may reflect a personality style that involves persistence and determination. How does a person determine their available resources? How do they determine whether they have spent their reserves or have more to call up? These are subjective experiences that are not well-understood. In addition, individual differences in responding may have less to do with physical resource limitations, and more to do with a person's natural style of responding including persistence, competitiveness or need for closure.

Participants under conditions of sleep loss have been asked to report the extent of effort they exerted when they responded on reaction time, vigilance, math addition, short-term memory and complex cognitive tasks. This wide range of domains in which subjective effort is measured indicate that measuring this construct is commonplace. Yet, reports of increased motivation and effort are not always related to improved performance (e.g., Odle-Dusseau et al., 2010). Moreover, participants who are sleep deprived do not reliably report increased effort exertion when compared with those who are fully-rested, despite sleep deprivation presumably compromising the resources necessary for effort. Reported effort has not differed under sleep and sleep loss conditions when assessed following addition tasks (Engle-Friedman et al., 2003), memory tasks (Drummond et al., 2000; Nilsson et al., 2005) and reaction time tasks (Nilsson et al., 2005) and object naming, basic arithmetic, and storytelling (Nilsson et al., 2005).

Subjective Effort: What Does It Mean?

What does it mean if a person, who has slept less than the amount they feel they need, reports increased effort on a task? This is a challenging question. The sleep-deprived person may report increased effort in performance when they are aware of a decrease in resource availability and tasks previously perceived to be easy now seem more difficult. Reports of greater effort following sleep deprivation could also reflect the activation of non-automatic, focused and voluntary alternative strategies to engage physiological, neurological, cortical and energetic resource reserves. It could also be a combination of the two or of other unaccounted experiences that occur when a person is asked to perform when there are limitations on their resource availability.

Notably, not only do tasks appear more effort-intensive following sleep loss, but participants also report putting forth less effort themselves. In other words, after insufficient sleep numerous tasks seems harder, and people reduce how hard they try to perform them. These reports could reflect the perception that the demands of the task are too onerous for the person given their sleep loss induced reduction in resources and the person has decided to eliminate the demand and conserve remaining resources. Trajectories of effort expenditure may rise with accumulated sleep loss and during the progression of assessment from early in the task period to late in the task period. Studies examining the time course of choice behavior will add to our understanding of how sleep affects resource capacity, how and when demands can be made on that capacity, when behavioral strategies are used to reduce the loss of that capacity, and when capacity is so severely expended that no effort can compensate.

Methodologically, the study of subjective effort needs greater rigor regarding the connection between the felt demand of the task, the perceived internal limitations, situations in which additional or alternative strategies are called-up, situations in which the task is abandoned and the language to describe those sensations and experiences. Subjective effort research in general and subjective effort research under sleep loss conditions thus requires an agreed upon a set of uniform questions clarified with specific instructions to be used across laboratories, under various conditions and tested for reliability. Such consistency in measurement might result in a consistent metric by which participants can share their experience of effort and by which researchers can understand that experience.

The Timing of Subjective Effort Assessment

The inconsistency in self-reported effort following sleep loss across labs may be a function of the variability in the time elapsed between the effort expenditure in the performance of a task and when the participant reports her feelings of effort expenditure. When self-reports of fatigue and mood are collected within the task period instead of collected at the rest break or after task completion, reports of fatigue are unsurprisingly greater (Heslegrave & Angus, 1985). No changes in effort reports may also reflect the vulnerability to interference of the memory of effort exertion (e.g. Drummond et al., 2000). In one study, when subjective reports of task difficulty and subjective effort on the learning task were collected 10 min after performance there were no differences in fully rested and participants deprived of 35 hours of sleep, and in a third study, it was unclear whether participants deprived of over 30 hours of sleep were able to recall their performance-related effort, and the rested and sleep deprived groups showed no difference on subjective reports of effort (Nilsson et al., 2005). The absence of differences in effort reports following full sleep and a night of no sleep could be a result of interference with and the loss of memory for the effort expended. Effort assessments occurring too long after the designated performance period has passed prevents the reliable assessment of the subjective experience when it was felt.

Individual Differences

Given the little known about the effort trajectory during sleep deprivation, it's not surprising that Hockey et al. (1998) found that in comparison to restful sleep, most participants reported expending more effort when sleep deprived while there were some who reported exerting less. Case studies give only a glimpse into the variability of the effort process. Case in point, two medical residents were monitored for effort and physiological indices over a 3-month period. One resident reported low workload, high levels of support and control, low levels of fatigue and anxiety and high levels of positive affective states. There was no relationship between subjective effort and cortisol, and adrenaline. The second resident's data showed a different picture. There was a relationship between subjective effort and cortisol, between subjective effort and noradrenaline, and between perceived work demands, fatigue, subjective effort and adrenaline (Hockey & Sauer, 1996). When considering these inconsistences in the how subjective effort is measured and whether it relates to performance (i.e., subjective-objective effort correlations), it becomes paramount to not only entertain methodological but also theoretical reasons for divergent findings. Specifically, more research should systematically examine how personality and individual differences affect how sleep impacts subjective effort, objective effort, and how well these variables correspond. Put simply, any subjective-objective effort correlations may be highly moderated by individual differences. Similarly, a direct relation between subjective effort and actual performance may also be obscured by moderating factors, including personality.

Physiological Vulnerabilities to Sleep Deprivation

The physiological determinants of effort reduction following sleep loss may be reflected in patterns of adenosinergic activity in the nucleus accumbens (NAcc). Waking central nervous system activity is coincident with elevated metabolism and increased concentrations of extracellular adenosine (Basheer, Strecker, Thakkar, & McCarley, 2004). During wakefulness increases in adenosine are correlated with subjective experiences of fatigue (Davis et al., 2003). During sleep, dramatic increases in cortical interstitial space allow for the removal of toxins including adenosine (Xie et al., 2013).

Receptors responsible for arousal inhibition and sleep promotion also control behavioral effort through a selective interaction between adenosine A2A receptors and antagonists of dopamine D2 receptors (Mingote et al., 2008). A2A antagonists can reverse the behavioral effects of dopamine antagonists on effort-related choice behavior (Salamone et al., 2013) suggesting that stress on this system may be responsible for fatigue and psychomotor slowing. Adenosinergic activity at the A2A receptors promotes sleep and effortful behavior is inhibited at the same synapses. Future studies examining the cascade responsible for reduced behavioral effort due to sleep loss may better clarify the influence of wakefulness generated adenosine, up-regulation of adenosine receptors at the NAcc after sleep deprivation, and the arousal inhibiting adenosinergic projections that affect effort.

Additional Future Directions

The previous section highlights unanswered questions relating to the physiological processes related to sleep and sleep loss. However, numerous future directions remain unexplored in broader areas of psychology. For example, given that the ability and willingness to engage in effortful cognition is compromised by sleep loss, while more automatic processes (e.g., behavioral and emotional impulsivity, stereotyping) are left unaffected, a broader integration with dual-processes theories in cognitive and social psychology is likely to be fruitful (see Satterfield, Raikes, and Killgore, chapter "Sleep in Social Cognition and Judgment", this volume). For example, a wealth of research has examined how decision making, reasoning, persuasion, and other tasks can be affected by either fast, effortless implicit processes or more cognitively taxing, effortful thinking (e.g., Smith & DeCoster, 2000). Thus, a broad prediction is that heuristics and implicit processes will become more powerful predictors of cognition and behavior as sleep quantity and quality decrease. This should be the case due to sleep loss compromising the ability and willingness to engage in effortful processes. As one specific instance, consider the domain of attitude change and persuasion. Here, the Elaboration Likelihood Model (Petty & Cacioppo, 1986) posits that peoples' attitudes can be altered through either peripheral or central cues. The former are implicit cues (e.g., spokesperson attractiveness, message framing) that lead to attitude change when a person is not thinking carefully about the persuasive message, while the latter (e.g., evidence, logical argumentation) will be most influential when a person is thinking carefully. It seems logical that sleep deprived individuals would be easily swayed by peripheral cues rather than central cues. Such findings would have both theoretical and applied implications.

Another promising future direction is examining how sleep loss affects a desire for interpersonal closeness and affiliation. Establishing and maintaining social bonds is a critical human motive (e.g., Baumeister & Leary, 1995). However, there are clues suggesting that this normally pervasive desire may be muted following sleep loss (e.g., increased irritability and interpersonal aggression). Accordingly, it would be interesting to examine more closely participants' interest in socialization relative to isolation both during and immediately following sleep deprivation. Such investigations would likely expand on the understanding of how sleep loss affects behavior in academic, organizational, and relationship contexts beyond what is currently known (and summarized above e.g., Kamphuis, et al., 2012; Moturu et al., 2011). For instance, employee performance on collaborative tasks may be especially impaired following poor sleep, not only because of the general cognitive impacts of sleep loss, but due to a decreased willingness to engage in social tasks. Similarly, the consequences of poor sleep on student absenteeism or drop out may be amplified in classes that require frequent group work if socializing is viewed as especially daunting or undesirable when sleep deprived. Future research will also benefit from a study of the broad societal impacts of sleep loss on behaviors that require effort. Those performing critical work in health and safety industries may make decisions under conditions of fatigue and sleep loss that may have serious impacts but would not be made if fully rested.

Conclusion

Sleep is a critical human function, and our capacity to function and execute tasks at work, school, and during social exchanges is determined in part by how much and how well we've slept. Nevertheless, sleep deprivation is commonplace, leading to decrements on tasks ranging from those dependent on low-level cognition to those requiring complex interpersonal skills. Commonplace across these domains is the need to exert effort of some kind (e.g., attention allocation, sustained engagement, accurate responding, deliberation) in order to maximize performance. Here is where poor or insufficient sleep disrupts performance: by virtue of compromising the resources and energy available to an organism, sleep loss prevents devoting sustained and effective effort. This can be seen in subjective reports of effort and in objective measures of behavior (e.g., time spent working on a task). Consequently, understanding how sleep affects task performance is of importance across various psychological areas, ranging from the study of basic cognitive processes (e.g., memory encoding and retrieval) to applied questions about organizational dynamics. The goals of this chapter include not only summarizing how sleep relates to effortful performance in these various domains, but also outlining methodological quandaries and fruitful next steps for sleep research.

References

Ackerman, P. L. (2011). 100 years without resting. In P. L. Ackerman (Ed.), *Cognitive fatigue* (pp. 47–66). Washington, DC: American Psychological Association.

Angus, R. G., & Heslegrave, R. J. (1985). Effects of sleep loss on sustained cognitive performance during a command and control simulation. *Behavior Research Methods, Instruments, & Computers, 17*, 55–67.

Balkin, T. J., & Badia, P. (1988). Relationship between sleep inertia and sleepiness: Cumulative effects of four nights of sleep disruption/restriction on performance following abrupt nocturnal awakenings. *Biological Psychology, 27*, 245–258.

Bargh, J. A., & Chartrand, T. L. (1999). The unbearable automaticity of being. *American Psychologist, 54*(7), 462–479. https://doi.org/10.1037/0003-066X.54.7.462

Bartoshuk, A. K. (1956). EMG gradients and EEG amplitude during motivated listening. *Canadian Journal of Psychology, 10*, 156–164.

Basheer, R., Strecker, R. E., Thakkar, M. M., & McCarley, R. W. (2004). Adenosine and sleep-wake regulation. *Progress in Neurobiology, 73*(6), 379–396. [PubMed].

Beck, R. C. (1990). *Motivation: Theories and principles*. Englewood Cliffs, NJ: Prentice Hall.

Blagrove, M., Alexander, C., & Horne, J. A. (1995). The effects of chronic sleep reduction on the performance of cognitive tasks sensitive to sleep deprivation. *Applied Cognitive Psychology, 9*, 21–40.

Carskadon, M. A., & Acebo, C. (2002). Regulation of sleepiness in adolescents: Update, insights, and speculation. *Sleep, 25*, 606–614.

Chelette, T. L., Albery, W. B., Esken, R. L., & Tripp, L. D. (1998). Female exposure to high G: Performance of simulated flight after 24 hours of sleep deprivation. *Aviation, Space, and Environmental Medicine, 69*, 862–868.

Chmiel, N., Totterdell, P., & Folkard, S. (1995). On adaptive control, sleep loss and fatigue. *Applied Cognitive Psychology, 9*, S39–S53.

Connor, J., Norton, R., Ameratunga, S., Robinson, E., Civil, I., Dunn, R., Bailey, J., Jackson, R. (2002). Driver sleepiness and risk of serious injury to car occupants: A population based case control study. *British Medical Journal, 324*, 1125–1128.

Cote, K. A., Mondloch, C. J., Sergeeva, V., Taylor, M., & Semplonius, T. (2014). Impact of total sleep deprivation on behavioural neural processing of emotionally expressive faces. *Experimental Brain Research, 232*(5), 1429–1442. https://doi.org/10.1007/s00221-013-3780-1. Epub 2013 Dec 8.

Dai, H., Milkman, K. L., Hofman, D. A., & Staats, B. R. (2015). The impact of time at work and time off from work on rule compliance: The case of hand hygiene in health care. *The Journal of Applied Psychology, 100*(3), 846–862. [PubMed].

Danziger, S., Levav, J., & Avnaim-Pesso, L. (2011). Extraneous factors in judicial decisions. *Proceedings of the National Academy of Sciences of the United States of America, 108*, 6889–6892. [PMC free article] [PubMed].

Davis, J. M., Zhao, Z., Stock, H. S., Mehl, K. A., Buggy, J., & Hand, G. A. (2003). Central nervous system effects of caffeine and adenosine on fatigue. *American Journal of Physiology. Regulatory, Integrative and Comparative Physiology, 284*(2), R399–R404. [PubMed].

Devine, P. G. (1989). Stereotypes and prejudice: Their automatic and controlled components. *Journal of Personality and Social Psychology, 56*(1), 5–18. https://doi.org/10.1037/0022-3514.56.1.5

Dewald, J. F., Meijer, A. M., Oort, F. J., Kerkhof, G. A., & Bögels, S. M. (2010, June). The influence of sleep quality, sleep duration and sleepiness on school performance in children and adolescents: A meta-analytic review. *Sleep Medicine Reviews, 14*(3), 179–189.

Dinges, D. F., Douglas, S. D., Zaugg, L., Campbell, D. E., McMann, J. M., Whitehouse, W. G., Orne,E. C., Kapoor, S.C., Icaza, E., Orne, M. T. (1994). Leukocytosis and natural killer cell function parallel neurobehavioral fatigue induced by 64 hours of sleep deprivation. *The Journal of Clinical Investigation, 93*, 1930–1939.

Donnell, J. (1969). Performance decrement as a function of total sleep loss and task duration. *Perceptual & Motor Skills, 29*, 711–714.

Drummond, S. P. A., Brown, G. G., Gillin, J. C., Stricker, J. L., Wong, E. C., & Buxton, R. B. (2000). Altered brain response to verbal learning following sleep deprivation. *Nature, 403*, 655–657.

Drummond, S. P. A., Meloy, M. J., Yanagi, M. A., Orff, H. J., & Brown, G. G. (2005). Compensatory recruitment after sleep deprivation and the relationship with performance. *Psychiatry Research: Neuroimaging, 140*, 211–223.

Durmer, J. S., & Dinges, D. F. (2005). Neurocognitive consequences of sleep deprivation. *Seminars in Neurology, 25*(1), 117–129.

Elsmore, T. F., Hegge, F. W., Naitoh, P., Kelly, T., Schlangen, K., & Gomez, S. (1995). A comparison of the effects of sleep deprivation on synthetic work performance and a conventional performance assessment battery. In *NHRC Rep. No. 95–96*. San Diego, CA: Naval Health Research Center.

Engle-Friedman, M. Hayrapetyan, L., Orodel, O., Loshak, M. (2018). *Do sleep problems affect what we eat?* Poster presented at the 21th annual meeting of the Associated Professional Sleep Societies, Minneapolis, Minnesota.

Engle-Friedman, M., Palencar, V., & Riela, S. (2010). Sleep and effort in adolescent athletes. *Journal of Child Health Care, 14*, 131–141.

Engle-Friedman, M., & Riela, S. (2004). Self-imposed sleep loss, sleepiness, effort and performance. *Sleep and Hypnosis, 6*, 155–162.

Engle-Friedman, M., Riela, S., Golan, R., Ventuneac, A. M., Davis, C. M., Jefferson, A. D., et al. (2003). The effect of sleep loss on next day effort. *Journal of Sleep Research, 12*, 113–124.

Fogt, D. L., Cooke, W. H., Kalns, J. E., & Michael, D. J. (2011). Linear mixed-effects modeling of the relationship between heart rate variability and fatigue arising from sleep deprivation. *Aviation, Space, and Environmental Medicine, 82*, 1104–1109.

Gais, S., Lucas, B., & Born, J. (2006). Sleep after learning aids memory recall. *Learning & Memory, 13*(3), 259–262.

Goldstein-Piekarski, A. N., Greer, S. M., Saletin, J. M., & Walker, M. P. (2015). Sleep deprivation impairs the human central and peripheral nervous system discrimination of social threat. *Journal of Neuroscience, 35*(28), 10135–10145.

Gordon, A. M., & Chen, S. (2014). The role of sleep in interpersonal conflict: Do sleepless nights mean worse fights? *Social Psychological and Personality Science, 5*(2), 168–175.

Gray, H. M., Mendes, W. B., & Denny-Brown, C. (2008). An in-group advantage in detecting intergroup anxiety. *Psychological Science, 19*(12), 1233–1237. https://doi.org/10.1111/j.1467-9280.2008.02230.x

Guadagni, V., Burles, F., Ferrara, M., Iaria, G. (2014). The effects of sleep deprivation on emotional empathy. *Journal of Sleep Research, 23*(6), 657–663. https://doi.org/10.1111/jsr.12192. Epub 2014 Aug 13.

Ghumman, S., & Barnes, C. M. (2013). Sleep and prejudice: a resource recovery approach. *Journal of Applied Social Psychology banner*, https://doi.org/10.1111/jasp.12045. First published: 09 May 2013

Harrison, Y., & Horne, J. A. (1997). Sleep deprivation affects speech. *Sleep, 20*, 871–877. https://doi.org/10.1093/sleep/20.10.871

Heslegrave, R. G., & Angus, R. J. (1985). The effects of task duration and work-session location on performance degradation induced by sleep loss and sustained cognitive work. *Behavior Research Methods, Instruments, & Computers, 17*, 592–603.

Hockey, G. R. J. (1997). Compensatory control in the regulation of human performance under stress and high workload. *Biological Psychology, 45*, 73–93.

Hockey, G. R., & Sauer, J. (1996). Cognitive fatigue and complex decision making under prolonged isolation and confinement. *Advances in Space Biology and Medicine, 5*, 309–330.

Hockey, G. R. J., Wastell, D. G., & Sauer, J. (1998). Effects of sleep deprivation and user interface on complex performance: A multilevel analysis of compensatory control. *Human Factors, 40*, 233–253.

Hoeksema-van Orden, C. Y., Gaillard, A. W., & Buunk, B. P. (1998). Social loafing under fatigue. *Journal of Personality and Social Psychology, 75*, 1179–1190.

Horne, J. A. (1998). *Why we sleep: The functions of sleep in humans and other mammals*. New York, NY: Oxford University Press.

Horne, J. A., & Pettitt, A. N. (1985). High incentive effects on vigilance performance during 72 hours of total sleep deprivation. *Acta Psychologica, 58*, 123–139.

Huck, N. O., Mcbride, S. A., Kendall, A. P., Grugle, N. L., & Killgore, W. D. S. (2008). The Effects of Modafinil, Caffeine, and Dextroamphetamine on Judgments of Simple Versus Complex Emotional Expressions Following Sleep Deprivation. *International Journal of Neuroscience, 118*(4), 487–502. Received 24 Aug 2006, Published online: 24 Aug 2009.

Jung, C. M., Melanson, E. L., Frydendall, E. J., Perreault, L., Eckel, R. H., & Wright, K. P. (2011). Energy expenditure during sleep, sleep deprivation and sleep following sleep deprivation in adult humans. *The Journal of Physiology, 589*, 235–244.

Kahneman, D. (1973). *Attention and effort* (pp. 28–42). Englewood Cliffs, NJ: Prentice Hall.

Kamphuis, J., Meerlo, P., Koolhaas, J. M., & Lancel, M. (2012). Poor sleep as a potential causal factor in aggression and violence. *Sleep Medicine, 13*(4), 327–334. https://doi.org/10.1016/j.sleep.2011.12.006. Epub 2012 Feb 1.

Kilgore, D. S., Balkin, T. J., & Wesensten, N. J. (2006). Impaired decision-making following 44 h of sleep deprivation. *Journal of Sleep Research, 15*, 7–13.

Killgore, W. D., Balkin, T. J., Yarnell, A. M., & Capaldi, V. F. (2017). Sleep deprivation impairs recognition of specific emotions. *Neurobiology of Sleep and Circadian Rhythms, 3*, 10–16.

Kjellberg, A. (1975). Effects of sleep deprivation on performance of a problem-solving task. *Psychological Reports, 37*(2), 479–485.

Knicker, A. J., Renshaw, I., Oldham, A. R., Simeon, P., & Cairns, S. P. (2011). Interactive processes link the multiple symptoms of fatigue in sport competition. *Sports Medicine, 41*, 307–328.

Krizan, Z., & Herlache, A. D. (2016). Sleep disruption and aggression: Implications for violence and its prevention. *Psychology of Violence, 6*(4), 542–552. https://doi.org/10.1037/vio0000018

Latane, B., Williams, K., & Harkins, S. (1979). Many hands make light work: The causes and consequences of social loafing. *Journal of Personality and Social Psychology, 37*, 822–832.

Laties, V. G. (1961). Modification of affect, social behavior and performance by sleep deprivation and drugs. *Journal of Psychiatric Research, 1*, 12–25.

Linder, J. A., Doctor, J. N., Friedberg, M. W., Reyes Nieva, H., Birks, C., Meeker, D., et al. (2014). Time of day and the decision to prescribe antibiotics. *JAMA Internal Medicine, 174*(12), 2029–2031. [PMC free article] [PubMed].

Ma, D. S., Correll, J., Wittenbrink, B., Bar-Anan, Y., Sriram, N., & Nosel, B. A. (2013). When fatigue turns deadly: The association between fatigue and racial bias in the decision to shoot. *Basic and Applied Social Psychology, 35*(6), 515–524.

Mingote, S., Font, L., Farrar, A. M., Vontell, R., Worden, L. T., Stopper, C. M., Port, R. G., Sink, K. S., Bunce, J. G., Chrobak, J. J., Salamone, J. D. (2008). Nucleus accumbens adenosine A2A receptors regulate exertion of effort by acting on the ventral striatopallidal pathway. *Journal of Neuroscience, 28*(36), 9037–9046. [PMC free article] [PubMed].

Moskowitz, G. B. (2010). On the control over stereotype activation and stereotype inhibition. *Social and Personality Psychology Compass, 4*(2), 140–158.

Moturu, S. T., Khayal, I., Aharony, N., Pan, W., & Pentland, A. (2011, August). Sleep, mood and sociability in a healthy population. In *Engineering in Medicine and Biology Society, EMBC, 2011 Annual International Conference of the IEEE* (pp. 5267–5270). IEEE.

National Sleep Foundation. (2005). Sleep in America TM poll: summary of findings cited 2016 Dec 1]. Available from: http://sleepfoundation.org/sites/default/files/2005_summary_of_findings.pdf/

National Sleep Foundation, Summary findings of the 2013 Sleep in America Poll. (2013). Arlington, VA.

National Sleep Foundation, Summary findings of the 2014 Sleep in America Poll. (2014). Arlington, VA.

Nilsson, J. P., Soderstrom, M., Karlsson, A. U., Lekander, M., Akerstedt, T., Lindroth, N. E., & Axelsson, J. (2005). Less effective executive functioning after one night's sleep deprivation. *Journal of Sleep Research, 14*, 1–6.

Odle-Dusseau, H. N., Bradley, J. L., & Pilcher, J. J. (2010). Subjective perceptions of the effects of sustained performance under sleep-deprivation conditions. *Chronobiology International, 27*, 318–333.

Palmer, C. A., & Alfano, C. A. (2017). Sleep and emotion regulation: An organizing, integrative review. *Sleep Medicine Reviews, 31*, 6–16. https://doi.org/10.1016/j.smrv.2015.12.006. Epub 2016 Jan 14.

Parkinson, B. (2005). Do facial movements express emotions or communicate motives?. *Personality and Social Psychology Review, 9*(4), 278–311.

Petty, R. E., & Cacioppo, J. T. (1986). The elaboration likelihood model of persuasion. In *Communication and persuasion* (pp. 1–24). New York, NY: Springer.

Pilcher, J. J., & Walters, A. S. (1997). How sleep deprivation affects psychological variables related to college students' cognitive performance. *Journal of American College Health, 46*, 121–126.

Proffitt, D. R. (2006). Embodied perception and the economy of action. *Perspectives on Psychological Science, 1*, 110–122.

Rechtschaffen, A., & Bergmann, B. M. (2002). Sleep deprivation in the rat: An update of the 1989 paper. *Sleep, 25*, 18–24.

Richards, P. M., & Ruff, R. M. (1989). Motivational effects on neuropsychological functioning: Comparison of depressed versus non-depressed individuals. *Journal of Consulting and Clinical Psychology, 57*, 396–402.

Rodgers, C. D., Paterson, D. H., Cunningham, D. A., Noble, E. G., Pettigrew, F. P., Myles, W. S., & Taylor, A. W. (1995). Sleep deprivation: Effects on work capacity, self-paced walking, contractile properties and perceived exertion. *Sleep, 18*, 30–38.

Russo, J. E., & Dosher, B. A. (1983). Strategies for multi-attribute binary choice. *Journal of Experimental Psychology. Learning, Memory, and Cognition, 9*, 676–696. PMID 6227682. https://doi.org/10.1037/0278-7393.9.4.676

Salamone, J. D., Correa, M., Randall, P. A., Nunes, E. J., Pardon, M., & Lopez-Cruz, L. (2013). The role of adenosine in the ventral striatal circuits regulating behavioral activation and effort-related decision-making: Importance for normal and pathological aspects of motivation. In S. Masino & D. Boison (Eds.), *Adenosine – a key link between metabolism and brain activity* (pp. 493–512). New York, NY: Springer.

Selvi, Y., Kiliç, S., Aydin, A., & Güzel Özdemir, P. (2015). The effects of sleep deprivation on dissociation and profiles of mood, and its association with biochemical changes. *Archives of Neuropsychiatry, 52*(1), 83–88.

Shaw, P. J. (2005). Thermoregulatory changes. In C. A. Kushida (Ed.), *Sleep deprivation: basic science, physiology and behavior*. New York, NY: Marcel Dekker.

Smith, E. R., & DeCoster, J. (2000). Dual-process models in social and cognitive psychology: Conceptual integration and links to underlying memory systems. *Personality and Social Psychology Review, 4*(2), 108–131.

Spiegel, K., Leproult, R., & Van Cauter, E. (1999). Impact of sleep debt on metabolic and endocrine function. *Lancet, 354*, 1435–1439.
Spiegel, K., Leproult, R., & Van Cauter, E. (2005). Metabolic and endocrine changes. In C. A. Kushida (Ed.), *Sleep deprivation: basic science, physiology and behavior*. New York, NY: Marcel Dekker.
Spiegel, K., Tasali, E., Penev, P., & Van Cauter, E. (2004). Brief communication: Sleep curtailment in healthy young men is associated with decreased leptin levels, elevated ghrelin levels, and increased hunger and appetite. *Annals of Internal Medicine, 141*, 846–850.
Steyvers, F. J. (1987). The influence of sleep deprivation and knowledge of results on perceptual encoding. *Acta psychologica, 66*(2), 173–187.
Steyvers, F. J., & Gaillard, A. W. (1993). The effects of sleep deprivation and incentives on human performance. *Psychological Research Psychologische Forschung, 55*, 64–70.
Stutts, J. C., Wilkins, J. W., & Vaughn, B. V. (1999). *Why so people have drowsy driving crashes? Input from drivers who just did*. Washington, DC: AAA Foundation for Traffic Safety.
Tefft, B. C. (2010). *Asleep at the wheel: The prevalence and impact of drowsy driving*. Washington, DC: AAA Foundation for Traffic Safety.
Tieleman, A. A., Knoop, H., van de Logt, A. E., Bleijenberg, G., van Engelen, B. G., & Overeem, S. (2010). Poor sleep quality and fatigue but no excessive daytime sleepiness in myotonic dystrophy type 2. *Journal of Neurology, Neurosurgery, and Psychiatry, 81*, 963–967.
Todd, P. M., Hertwig, R., & Hoffrage, U. (2015). Evolutionary cognitive psychology. In *The handbook of evolutionary psychology* (pp. 1–19).
Wallerstein, H. (1954). An electromyographic study of attentive listening. *Canadian Journal of Psychology, 8*, 228–238.
Wilkinson, R. (1961). Interaction of lack of sleep with knowledge of results, repeated testing and individual differences. *Journal of Experimental Psychology, 62*, 263–271.
Xie, L., Kang, H., Xu, Q., Chen, Thiyagarajan, M., O'Donnell, J., Christensen, D. J., Nicholson, C., Iliff, J. J., Takano, T., Deane, R., Nedergaard, M. (2013). Sleep drives metabolite clearance from the adult brain. *Science, 342*, 373–377.