Brain and Cognition 94 (2015) 17–23

Contents lists available at ScienceDirect

Brain and Cognition

journal homepage: www.elsevier.com/locate/b&c

Partial sleep deprivation does not alter processes involved in semantic word priming: Event-related potential evidence

Paniz Tavakoli[a], Alexandra Muller-Gass[a,b], Kenneth Campbell[a,*]

[a] *School of Psychology, University of Ottawa, Canada*
[b] *Defence Research and Development Canada, Toronto, Canada*

ARTICLE INFO

Article history:
Accepted 17 December 2014
Available online 23 January 2015

Keywords:
Partial sleep deprivation
Semantic priming
Cognitive strategy
Performance measures
Event-Related Potentials
N400

ABSTRACT

Sleep deprivation has generally been observed to have a detrimental effect on tasks that require sustained attention for successful performance. It might however be possible to counter these effects by altering cognitive strategies. A recent semantic word priming study indicated that subjects used an effortful predictive-expectancy search of semantic memory following normal sleep, but changed to an automatic, effortless strategy following total sleep deprivation. Partial sleep deprivation occurs much more frequently than total sleep deprivation. The present study therefore employed a similar priming task following either 4 h of sleep or following normal sleep. The purpose of the study was to determine whether partial sleep deprivation would also lead to a shift in cognitive strategy to compensate for an inability to sustain attention and effortful processing necessary for using the predicative expectancy strategy. Sixteen subjects were presented with word pairs, a prime and a target that were either strongly semantically associated (*cat*...*dog*), weakly associated (*cow*...*barn*) or not associated (*apple*...*road*). The subject's task was to determine if the target word was semantically associated to the prime. A strong priming effect was observed in both conditions. RTs were slower, accuracy lower, and N400 larger to unassociated targets, independent of the amount of sleep. The overall N400 did not differ as a function of sleep. The scalp distribution of the N400 was also similar following both normal sleep and sleep loss. There was thus little evidence of a difference in the processing of the target stimulus as a function of the amount sleep. Similarly, ERPs in the period between the onset of the prime and the subsequent target also did not differ between the normal sleep and sleep loss conditions. In contrast to total sleep deprivation, subjects therefore appeared to use a common predictive expectancy strategy in both conditions. This strategy does however require an effortful sustaining of attention, and may not have been entirely successful when sleep was restricted. A slight but significant decrease in accuracy was noted.

1. Introduction

Sleep deprivation has been consistently shown to degrade performance on many cognitive tasks especially for those that require sustained attention for successful completion (reviewed by Lim & Dinges, 2010). Not all studies however find this decline in performance perhaps because subjects may be able to compensate for the effects of sleep deprivation by altering cognitive strategies (Drummond et al., 2005; Lim & Dinges, 2008).

Recently, López-Zunini, Muller-Gass, and Campbell (2014) provided empirical evidence of dynamic changes in cognitive strategy after subjects had been totally sleep deprived. They employed a word priming task in which an initial word (the "prime") appeared and subsequently followed by a "target" word that was either strongly (e.g., *cat*...*dog*), weakly (*cow*...*barn*), or not semantically associated (*apple*...*road*) with the prime. The subject's task was to determine if the target was in fact semantically associated with the prime. Following normal sleep, the usual priming advantage was found. Reaction times (RTs) were faster and accuracy was higher following presentation of strongly primed targets. The strong priming advantage was still maintained following total sleep deprivation (TSD), although there was a small non-significant overall deterioration in accuracy.

Priming tasks are especially useful for the study of sleep deprivation because the similarity in performance that López-Zunini et al. observed can be obtained through the use of two very different cognitive strategies. Their results suggest that subjects might have used one strategy following normal sleep but then switch

---

* Corresponding author at: School of Psychology, University of Ottawa, Ottawa K1N 6N5, Canada.

E-mail address: kenneth.campbell@uottawa.ca (K. Campbell).

http://dx.doi.org/10.1016/j.bandc.2014.12.003
0278-2626/Crown Copyright © 2015 Published by Elsevier Inc.

to a different strategy to maintain performance following total sleep deprivation. Most cognitive researchers agree that the presentation of the prime activates a semantic memory network with strongly associated semantic concepts represented in neighboring nodes and weakly associated concepts represented in more distant nodes. Targets that are not associated with the prime are not represented in the semantic network and are thus not available to memory prior to their onset (Collins & Loftus, 1975; Neely, 1991). The search is completed more rapidly for strongly associated targets than for either weakly associated or unassociated targets. The extent to which effortful processing is required to search the semantic network is disputed. One theory proposes that the subject can use the prime to intentionally predict a set of semantically associated target candidates (Becker, 1980; Neely, 1976; Posner & Snyder, 1975). There is however a cost to the use of this strategy as it requires active and effortful processing in order to generate possible target candidates and maintain them in working memory. This strategy would be appropriate following normal sleep, when sufficient cognitive resources are readily available. The use of an effortful expectancy-predictive strategy was promoted in the López-Zunini et al. study by having subjects intentionally determine if the target was associated with the prime. Moreover, the time between the onset of the prime and the target was 700 ms, long enough to permit the use of this strategy. A second theory proposes that the search of semantic memory can be initiated automatically and effortlessly, without the need for active and sustained attention (Collins & Loftus, 1975). This strategy could thus have been used to maintain performance following sleep deprivation when considerably fewer cognitive resources were presumably available.

López-Zunini et al. also recorded event-related potentials (ERPs) following the presentation of the primes and targets to monitor in real-time whether performance following sleep deprivation was maintained through the use of a similar or different cognitive strategy compared to that employed following normal sleep. In the normal sleep condition, a negative-going waveform peaking at about 400 ms (thus the “N400”) following presentation of the target was much larger when it was not semantically associated with the prime, a finding replicating many others (reviewed by Kutas & Federmeier, 2011). This was also however the case in the TSD condition. Importantly, the overall N400 across all stimulus types was significantly reduced following TSD. Holcomb (1988) had previously noted that the use of an automatic, effortless search of semantic memory will result in a reduction of the N400 compared to when an effortful, intentional search is employed. Thus, the difference in the overall N400 amplitude following TSD might be explained by a change from an effortful to a relatively effortless cognitive strategy. The use of different cognitive strategies should have especially been apparent between the presentation of the prime and the subsequent target words, the time when the semantic network is searched. A long-lasting negativity beginning at about 300 ms following the prime and continuing until the onset of the target word was indeed significantly larger in the normal sleep condition. This might reflect additional effortful processing or may be a reflection of a so-called contingent negative variation (CNV) which has long been known to be attenuated following sleep deprivation (Naitoh, Johnson, & Lubin, 1971).

While total sleep deprivation conditions are often employed in the study of the cognitive effects of sleep loss, in real-life situations, total sleep deprivation occurs much less frequently than partial sleep deprivation. The American Centers for Disease Control (CDC) analyzed data obtained from interviews on more than 15,000 workers and indicated that more than 30% of its sample slept on average for less than 6 h a day (CDC, 2012). Sleep restriction is thus a hallmark of modern society due to a broad range of societal and medical factors such as recreational opportunities, work schedules and sleeping disorders. In many cases, sleep is delayed, such that the onset of sleep begins later than normal.

While partial sleep deprivation occurs much more often than total sleep deprivation, relatively few studies have examined its effects on cognitive processing. The results of studies investigating partial sleep deprivation are less consistent although tasks that require sustained attention are more likely to show a deterioration in performance (see Dinges, Rogers, & Baynard, 2005; Shekleton, Rogers, & Rajaratnam, 2010 for reviews). When partial sleep deprivation does affect performance, the effects are generally reduced compared to TSD (Casement, Broussard, Mullington, & Press, 2006; Otmani, Pebayle, Roge, & Muzet, 2005; Van Dongen, Maislin, Mullington, & Dinges, 2003). The effects may vary with the extent of sleep deprivation (Belenky, Wesensten, Thorne, et al., 2003) and can affect ERPs related to both automatic and controlled aspects of attention (Zerouali, Jemel, & Godbout, 2010).

The present study examines the effect of 4 h of sleep on the word priming task used by López-Zunini et al. The interest is whether a common strategy will be used in the normal and partial sleep condition or whether, as was the case with TSD, a different cognitive strategy will be adopted to maintain consistent performance following partial sleep deprivation.

2. Methods

2.1. Subjects

Sixteen young adults (10 females) between the ages of 20 and 30 years (Mean = 23.1, SD = 2.9 years) volunteered to participate in this study. All were right-handed, with good self-reported health, normal or corrected-to-normal eyesight and were not taking any medications known to affect cognitive function. None had any history of neurological or psychiatric disorder. Absence of sleep disorders was verified using the Pittsburgh Sleep Index (Buysse, Reynolds, Monk, Berman, & Kupfer, 1989). Subjects were required to maintain a regular sleep schedule (no night or shift work). Subjects were asked to abstain from alcohol and caffeine in the 24 h period prior to the start of data collection. This study was conducted following the guidelines of the Canadian Tri-Council (Health, Natural, and Social Sciences) on ethical conduct involving humans. All subjects gave written informed consent prior to the beginning of the experiment and were paid an honorarium for their participation.

2.2. Procedure

All subjects participated in two experimental sessions, one following a normal night of sleep, and one following partial sleep deprivation. The order of the sessions was counterbalanced across subjects and at least one week separated the two sleep conditions.

Subjects were asked to retire for sleep at their normal bedtime and to awaken at their normal wake time for four consecutive nights prior to both normal sleep and sleep deprivation sessions. They completed sleep logs each morning upon awakening. The sleep logs were subsequently verified to assure compliance. The sleep patterns did not differ prior to the normal sleep and sleep deprivation sessions. On the sleep-deprived night, subjects were instructed to sleep at 03:00 and were awakened at 07:00. Subjects were required to wear a wrist actigraph on the night prior to testing. Subsequent analyses of the actigraph data did indicate that subjects followed this sleep schedule. Data collection began the following morning between 08:00 and 10:00. While awake at night, subjects played computer games or watched videos/television. Upon coming to the lab in the morning, subjects completed the Stanford Sleepiness Scale, a 7-point rating scale (1 = awake and alert, 7 = falling asleep).