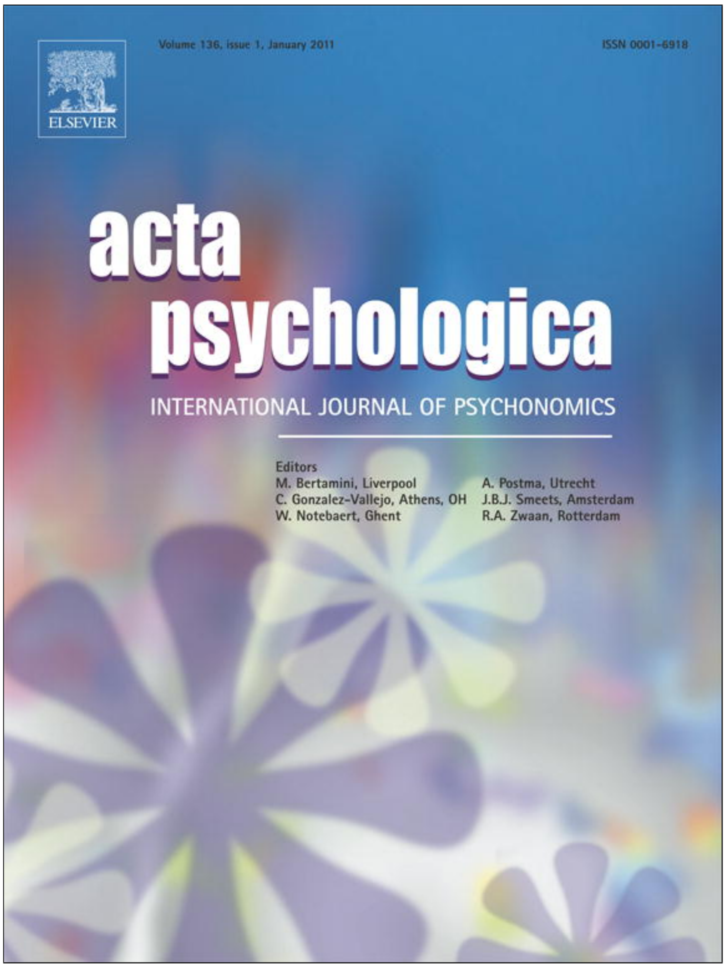
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Minimizing sleep deprivation effects in healthy adults by differential outcomes

Diana Martella [a,*], Victoria Plaza [b], Angeles F. Estévez [c], Alejandro Castillo [b], Luis J. Fuentes [b,*]

[a] Basque Center on Cognition, Brain and Language, San Sebastián, Spain
[b] Departamento de Psicología Básica y Metodología, Universidad de Murcia, Spain
[c] Departamento de Neurociencia y Ciencias de la Salud, Universidad de Almería, Spain

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ABSTRACT

Sleep deprivation reduces vigilance or arousal levels, affecting the efficiency of certain cognitive functions such as learning and memory. Here we assessed whether the differential outcomes procedure (DOP), a learning procedure that has proved useful to ameliorate episodic memory deficits, can also improve memory performance in sleep-deprived participants. Photographs were presented as sample faces. A probe face was then presented for recognition after either short or long delays. In the differential outcomes condition a unique reinforcer followed correct responses. In the non-differential outcomes condition reinforcers were provided in a random manner. The results indicated that the DOP prevented the recognition memory to decrement during the long delay in the control group, replicating previous findings. The sleep-deprived group showed DOP benefits mainly with the short delay, when working memory could be affected by low arousal. These findings confirm that the DOP can overcome impaired recognition memory due to sleep deprivation conditions.

Sleep deprivation – a complete lack of sleep during a certain period of time or a shorter sleep time (e.g., Orzeł-Gryglewska, 2010) – may be a result of the contemporary lifestyle or works requiring continuous performance for extended periods (i.e., a physician in an intensive care unit, a pilot during intense operations) (Barger et al., 2006) and affects many people. Without adequate sleep, people usually experience difficulties in performing effectively at work, carrying out habitual home duties or driving a vehicle safely. On the basis of these difficulties, it has been suggested sleep loss reduces the vigilance or arousal level, producing a general worsening in cognitive performance (Chee et al., 2008; Tomasi et al., 2009). As a consequence, the study of sleep deprivation (SD) can represent a fruitful area of research to increase our knowledge about cognitive functions and their neural basis. Also, a better understanding of SD would be useful in applied areas, such as accident prevention, since lack of sleep is considered a major cause of road traffic accidents, especially at night (Åkerstedt, Philip, Capelli, & Kecklund, 2011; Lal & Craig, 2001).

Performance impairments can occur during the first night without sleep (Monk & Carrier, 1997), and are amplified after two nights of sleep deprivation (How et al., 1994). Such deficits can be observed in both simple and complex tasks (e.g., verbal fluency, logical reasoning, decision making and judgment) (Gillberg & Akerstedt, 1998; Harrison & Horne, 1999, 2000). In tasks involving working memory, the sleep loss leads to difficulty defining the task goals due to distracting information (Blagrove, Cole-Morgan, & Lambe, 1994; Horne, 1988), remembering the temporal order of information (Harrison & Horne, 2000), maintaining flexible thinking, and making performance modifications based on new information (Harrison & Horne, 1999). Furthermore, it is worth noting that some memory tasks are differently affected by sleep loss. For example, Drummond et al. (1999) observed that sleep deprived participants showed poorer performance and reduced activation in the prefrontal cortex than controls in an arithmetic task involving working memory. In another study, Harrison and Horne (2000) reported that recognition memory for faces was unaffected by 35 h of sleep deprivation. However, although these participants remembered that the faces were familiar, they had problems remembering in which of two sets of photos the faces had appeared, suggesting a selective worsening of contextual memory. Using a similar task, Mograss, Guillem, Brazzini-Poisson, and Godbout (2009) observed no detrimental effects of one night of sleep deprivation on behavioral data, but ERP analyses revealed decreased amplitude of components associated to stimulus discrimination in long-term memory due to impaired processing of details.

Given that sleep deprivation affects working memory, and people who work or study at night can suffer from sleep loss, any procedure that improves learning and memory might be helpful for these people. The differential outcomes procedure (hereafter the DOP) might be such a procedure.

The DOP was originally used in animal learning studies and proved useful in conditional discrimination tasks. In these tasks,

* Corresponding authors at: Departamento de Psicología Básica y Metodología, Facultad de Psicología, Universidad de Murcia, Campus de Espinardo, 30100 Murcia, Spain. Tel.: +34 868 88 41 40; fax: +34 868 88 41 11.
E-mail addresses: d.martella@bcbl.eu (D. Martella), vplaza@um.es (V. Plaza), mafernan@ual.es (A.F. Estévez), acastillo@um.es (A. Castillo), lfuentes@um.es (L.J. Fuentes).

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sample stimuli are followed by comparison choices, and participants are required to learn the correct sample/choice combination. Under differential outcomes conditions participants are reinforced with a distinct outcome for each correct choice. When this training procedure is applied, learning is faster and final accuracy is higher than when the reinforcers are randomly presented (the non-differential outcomes procedure), or when only one kind of reinforcer is used for all correct responses. This enhancement of accuracy and acquisition observed when specific outcomes are arranged has been called the differential outcomes effect (Trapold, 1970; Trapold & Overmier, 1972). Shepp (1962, 1964) was one of the first authors to suggest a possible positive effect of the DOP on human learning. More recently, the DOP has been shown to be effective in adults with Prader-Willi syndrome (Joseph, Overmier, & Thompson, 1997), and low IQ (Estévez, Overmier, Fuentes, & González, 2003; Malanga & Poling, 1992), as well as those without mental handicaps (Easton, 2004; Estévez et al., 2007; Legge & Spetch, 2009; Miller, Waugh, & Chambers, 2002). In addition, this training benefit was extended to normal children (Estévez & Fuentes, 2003; Estévez, Fuentes, Marí-Beffa, González, & Alvarez, 2001; Maki & Overmier, 1995; Martínez, Estévez, Fuentes, & Overmier, 2009), to children born prematurely (Martínez et al., 2012) as well as to children and adults with Down syndrome (Estévez et al., 2003).

Importantly for the purposes of the present study, the DOP can also be arranged to improve memory-based task performance. Indeed, previous studies have shown that the DOP improves memory recognition performance in young adults (Plaza, Estévez, Lopez-Crespo, & Fuentes, 2011), aged people (López-Crespo, Plaza, Fuentes, & Estévez, 2009) and adults with alcohol related amnesia (Hochhalter, Sweeney, Bakke, Holub, & Overmier, 2000).

A recent explanation of the benefical effect of the differential outcomes procedure refers to the two-memory systems model (Savage & Ramos, 2009). When non-differential outcomes are arranged, there is only one source of information that can guide correct choice behavior, the retrospective recall of the particular discriminative stimulus. Conversely, under differential outcomes procedures, it is the prospective memory of what the upcoming reward will be what might guide correct choice behavior (e.g., Overmier, Savage, & Sweeney, 1999; Ramirez, Buzzetti, & Savage, 2005; Savage, 2001; Savage & Parsons, 1997). Such prospective memory (or reward expectancy) elicited by the discriminative stimulus is thus critical to the enhancement of choice behavior observed in the differential outcomes condition. There are some studies (e.g., Einsten & McDaniel, 2005; McDaniel & Einstein, 2000) suggesting that prospective memory is a relatively automatic process based on an involuntary automatic associative memory system. Also, it has been proposed that sleep deprivation may be more detrimental to the endogenous (voluntary) processes while the exogenous (automatic) processes will be more resistant (e.g., Trujillo, Kornguth, & Schnyer; 2009). As a consequence, we expected that the DOP would preserve memory performance from the sleep loss effects, by means of the automatic component of the prospective memory.

The aim of the present study is to assess whether the DOP can be an effective technique for improving recognition memory under moderate sleep deprivation conditions (i.e., the first hours of the night without sleep). For this purpose we used a delayed face recognition task under differential and non-differential conditions, with a group of sleep-deprived participants and a group of non sleep-deprived participants (controls) (see Fig. 1 for a graphical representation of the task design).

The control participants performed the task at 8.00 pm with maximum level of arousal, and sleep-deprived participants performed the task at 4.00 am with minimum level of arousal. These two time windows correspond to the main "sleep gate" (i.e., the minimum level of arousal) and the "forbidden zones for sleep" (the maximum level of arousal), described by Lavie (2001). Specifically, the author observed a bimodal distribution of sleepiness: a major nocturnal sleepiness crest and a secondary mid-afternoon sleepiness peak. These are separated by a "forbidden zone" for sleep centered at around 20.00–22.00 h. It is important to note that when participants are required to stay awake beyond their usual sleep onset time, performing tasks during night-time, i.e. when a main sleep gate occurs, two potential sources of influence may affect the decrease of vigilance: one is sleep loss per se and the other is the circadian factor (i.e., night-time hours; Lavie, 2001). This type of sleep deprivation paradigm is particularly useful because it leads to a decrease of vigilance (Casagrande et al., 2006) in a rather ecologically valid way and can better assess the effects of vigilance reduction that several shift workers usually undergo. Here we refer to "sleep deprivation" as a condition characterized by impaired vigilance due to sleep loss and circadian factors.

On the basis of previous findings (e.g., Martella, Casagrande, & Lupiáñez, 2011), we expected longer reaction times (RTs) and a higher percentage of incorrect responses in sleep-deprived than in control participants, due to reduced vigilance in the former compared with the latter group. Importantly, we hypothesized that the implementation of the DOP in the present task would improve face recognition performance in control participants, especially in conditions where working memory is more demanding (e.g., with long delays). As sleep loss is expected to exert a detrimental effect on recognition memory in sleep-deprived participants, even at short delays, the DOP is also expected to ameliorate such expected memory impairments.

1. Method

1.1. Participants

Sixty undergraduate students (mean age = 21.67 ± 5.54; 34 women) signed an informed consent before participating in the study. They were compensated either with 30€ (sleep-deprived participants) or course credits (control participants) for their participation. All participants were right-handed and reported normal or corrected-to-normal vision. The local ethical committee approved the study.

1.2. General procedure

Participants were asked to complete a daily sleep questionnaire upon final awakening in the morning, for one week before the experimental session. To be eligible for the experiment, participants had to be non-smokers and drug-free, and report normal sleep duration (7.5–8.5 h per day) and schedule (going to sleep at 11.30 pm ± 60 min, and waking up at 7.30 am ± 60 min). In addition, those that had sleep, medical, or psychiatric disorders were not included in the study. During the experimental session, participants did not drink or eat anything containing caffeine (e.g., coffee, tea, chocolate) and were behaviorally monitored at all times by trained research assistants. Participants had two breaks, one for lunch (about 2.00 pm) and one for dinner (about 9.00 pm).

Participants were randomly assigned either to the sleep deprivation group (n = 26) or to the control group (n = 34). Within each group, half of the participants ran the task under the differential outcomes condition and half under the non-differential outcomes condition. On the day of the experiment, all participants arrived at the lab at 9.00 am. The control participants stayed in the lab until 9.00 pm, while the sleep deprived participants stayed until 12.00 am of the following day. Before the delayed face recognition task, all participants performed other cognitive tasks (e.g., attentional and memory tasks). The sleep deprived participants performed the task at 4.00 am, and the control participants at 8.00 pm.

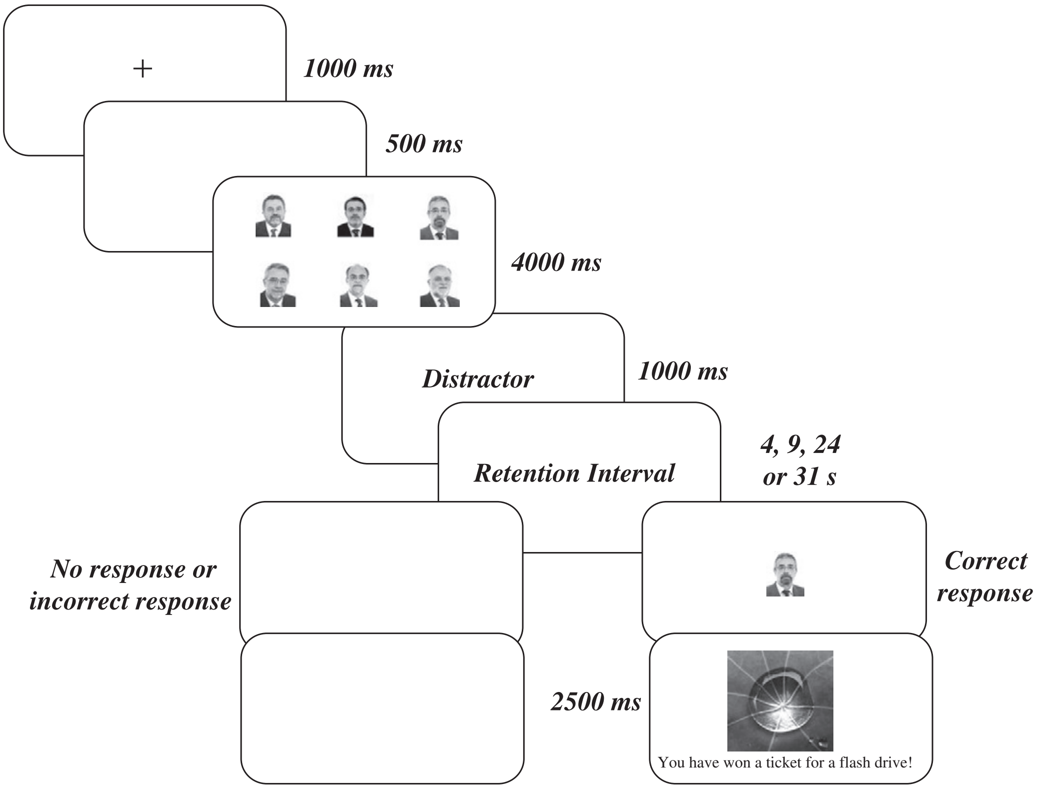

Fig. 1. Stimuli sequence (from left to right) used in experiment.

1.3. Apparatus and stimuli

Color photographs of male faces taken in full-face view directly facing the camera were used as both samples and choices. Photographs were presented on a dark background on a color monitor (VGA) of an IBM/PC compatible computer. The E-Prime program (Psychology Software Tools, 1999) controlled stimulus presentation and registered latency and accuracy data.

The photographs measured 5.5 × 6.5 cm and could be displayed either grouped in a 3 × 2 grid (sample faces) or individually in the center of the screen (probe face), equidistant from the borders. The position of the photographs on the 3 × 2 grid was randomly arranged throughout the entire experiment. Six pictures of a landscape served as secondary reinforcers along with the phrase "You have won a ticket for (the name of a specific primary reinforcer or outcome)". A pen drive, a CD pack, a DVD pack, a book, a game and a CD wallet, were used as primary reinforcers. Reinforcers were raffled off at the end of the experiment.

1.4. Experimental procedure

The test consisted of 96 trials grouped into two blocks of 48 trials each. On each trial a central fixation point (an asterisk) appeared for 1000 ms. After an interval of 500 ms six faces (sample stimuli) were presented for 4000 ms. Then, participants were instructed to count backwards aloud by threes until the probe face (choice stimulus) was presented. The interval between the sample faces and the probe face was set at 5, 10, 25 or 32 s (randomly selected on a given trial). The probe face was presented for 10 s or until a response was made. The participants had to decide whether the probe face was present among the six sample faces. For affirmative responses, participants were required to press the "N" key on the computer keyboard, and the M key for negative responses. On half of trials one of the sample faces was also presented as the probe face (YES trials), and the remaining half of the trials, none of the six sample faces repeated as the probe face (NO trials). Following a correct response both a picture of a landscape and a phrase appeared on the screen for 2500 ms. Should the response be incorrect the next trial began after an interval of 2500 ms (see Fig. 1). The trial was also scored as incorrect if participant did not produce a response within 10 s after the probe face presentation (see Plaza et al., 2011, Experiment 2b, for further details). Participants from both groups were tested individually in a quiet room. The instructions for the experiment were provided both by a written text on the computer screen and verbally by the experimenter. After reading the instructions, participants practiced the task to ensure correct understanding of the instructions. The task consisted of two experimental blocks, each one lasted about 20 min.

Participants in the differential outcomes condition consistently received specific outcomes following correct recognition responses. Each correct sample/probe combination was always associated with a particular and unique outcome, that is, one of the six possible picture-phrase pairs (e.g., the picture of a mountain and the phrase "You have won a ticket for a book"). The participants in the non-differential outcomes condition were also rewarded for correct choices, but outcomes were randomized with respect to the particular face so that each probe face in that condition was associated with all six-reward combinations used in the experiment.

2. Results

Table 1 shows accuracy and latency data for each group of participants in all experimental conditions. Percentages of correct responses and median correct RTs were submitted to 2 × 2 × 2 mixed ANOVAs with *group* (sleep deprived, control) and *condition* (differential outcomes, non-differential outcomes) as between-subjects factors, and *delay* (short, long) as the within-subjects factor. Since there were no statistical differences between delays of 5 and 10 s and delays of 25 and 32 s, respectively, we collapsed the four levels of the variable into short (5, 10 s) and long (25, 32 s) delays.

Table 1
Mean percentages of correct responses, standard error of the mean (SE) and mean median correct RTs (in milliseconds) obtained by participants in the task as a function of Delay (5, 10, 25 and 32 s) and Outcomes (differential and non-differential).

Group	5 s delay		10 s delay		25 s delay		32 s delay	
	M	SE	M	SE	M	SE	M	SE
Correct responses								
Sleep deprived								
Differential	59.08	3.46	61.23	2.83	56.54	3.02	54.54	2.39
Non-differential	47.85	3.46	52.00	2.83	52.77	3.02	50.00	2.39
Controls								
Differential	67.0	10.84	66.58	7.11	61.82	10.84	57.82	9.08
Non-differential	59.88	16.35	62.17	12.54	53.82	9.10	57.88	10.92
Reaction times								
Sleep deprived								
Differential	1360.73	109.75	1441.23	115.69	1481.27	139.44	1466.65	131.67
Non-differential	1594.54	109.75	1562.00	115.69	1753.35	139.44	1659.77	131.67
Controls								
Differential	1504.94	207.97	1518.17	309.86	1615.17	387.99	1637.26	430.82
Non-differential	1537.0	521.2	1432.85	430.25	1492.55	477.27	1568.15	491.46

2.1. Accuracy analysis

We observed main effects of *group*, $F(1,56)=13.54$; $p<.001$, *condition*, $F(1,56)=11.43$; $p<.001$, and *delay*, $F(1,56)=5.68$; $p<.02$. Accuracy was higher for control than for sleep-deprived participants (62% vs. 54%), under differential than non-differential conditions (61% vs. 54%), and with short than long delays (59% vs. 56%). In order to better understand the performance of the control and sleep-deprived group, further statistical analyses were separately carried out for the two groups. For the control group, the analyses showed significant main effects of *condition*, $F(1,32)=5.83$; $p<.02$, and *delay*, $F(1,32)=5.17$; $p<.03$, but not their interaction (see Fig. 2). For the sleep-deprived group, recognition memory was at the chance level under the non-differential outcomes condition at both delays ($ps>.05$). The differential outcomes condition increased performance by an average 7%, although the improvement was more pronounced with the short than with the long delay. These results were qualified by the significant *condition* × *delay* interaction, $F(1,24)=5.33$; $p<.03$.

2.2. Reaction time analysis

The analyses conducted on latency data showed a main effect of *delay*, $F(1,56)=15.44$; $p<0.001$), indicating shorter RTs with short than with long intervals (1494 vs. 1594 ms). No other main effects or interactions reached statistical significance.

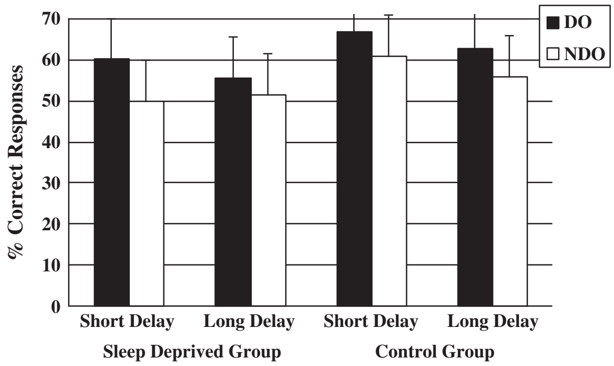

Fig. 2. Mean percentage of correct responses for control and sleep deprived groups at short and long delay under differential and non-differential outcomes. DO = differential outcomes; NDO = non-differential outcomes.

3. Discussion

In the present research we assessed whether the DOP is a useful instrument to ameliorate working memory deficits usually associated with sleep deprivation (Harrison & Horne, 2000; Mograss et al., 2009). The rational for combining two different fields of research is that any procedure that can help people whose work or activities lead to some sleep loss would be very important. According to the present findings the DOP improves the performance of the task, at least in face recognition tasks such as the one used here.

Findings with the control group replicated our previous findings (Plaza et al., 2011). Results showed that face recognition memory performance of healthy adults was more accurate when they received differential outcomes following their correct responses. As expected, participants were less accurate and slower in their correct responses at the longer delay, but the delay never interacted with reward condition indicating that the DOP enhanced performance equally at all delay intervals.

This protective function of the DOP has been also observed with aged people (López-Crespo et al., 2009) and even with people diagnosed with Alzheimer's disease (Plaza et al., submitted). Findings with sleep-deprived participants suggest that the face recognition task used here was very difficult to perform under sleep loss. Contrary to control participants, the percentage of correct responses was at chance level for both short and long delays under the non-differential outcomes condition. In other words, participants were not able to recognize faces that were displayed only 5/10 s before. However, the DOP increased recognition memory, mainly with short delays.

In order to account for the present results, we should take into account the two different memory processes involved in delayed memory tasks. It has been proposed that under non-differential outcomes conditions, the only source of information that can guide the correct response is a retrospective process that maintains the discriminative stimulus over the delay (Savage, Pitkin, & Careri, 1999). With long delays maintenance of the discriminative stimulus becomes harder and therefore more demanding of working memory processes. In this case, conditions that affect working memory functioning, such as sleep loss, would produce detrimental effects on memory task performance. However, under differential outcomes conditions, participants would have an additional source of information to perform the task. Specifically, a prospective memory process would keep the trace active for events expected to occur after the delay (e.g., response/unique outcome; Mok, Thomas, Lungu, & Overmier, 2009). Thus, such prospective process provide an additional beneficial cue for forming the association between the correct response and the discriminative stimulus, and it can help to overcome any deficiency in working memory functioning.

Some animal studies have shown that different brain regions are recruited when differential and non-differential outcomes are employed (for a review, see Savage & Ramos, 2009). When trained with the non-differential outcomes procedure, the animal only has access to a memory for the discriminative stimulus, thus only requiring activation of the hippocampus for retrieval (Savage, Buzzetti, & Ramirez, 2004), suggesting that the hippocampus plays a role in mediating retrospective rather than prospective memory. On the other hand, under differential outcomes the basolateral amygdala and the orbitofrontal cortex are critical for both development and maintenance of expectancies produced by the DOP (Ramirez & Savage, 2007). Thus, this cortical region appears to mediate prospective processing. These results are confirmed by a recent fMRI study with healthy adults (Mok et al., 2009).

Regarding the effects of sleep deprivation, several studies have shown that the prefrontal cortex is particularly sensitive to sleep loss (Belenky et al., 2003; Drummond et al., 1999; Thomas et al., 2000) and that a period of moderate sleep deprivation (<48 h) can negatively affect learning and memory abilities (Mograss et al., 2009). For example, Yoo, Gujar, Hu, Jolesz, and Walker (2007) observed that sleep-deprived participants exhibited a striking 40% reduction in the ability to form new memories. On the basis of these findings, it could be hypothesized that the DOP might overcome the impairment in learning and memory observed under sleep deprivation conditions. Admittedly, the DOP was more efficient under short than long intervals in sleep-deprived participants. It might be that sleep deprivation also reduces something required to entirely overcome the need of the retrospective process: the ability to form an implicit association between the correct response and the specific reinforcer. It could be attributed to the fact that the areas involved in prospective memory are the same to those involved in sustained or tonic alertness (frontal and parietal areas; Sturm & Willmes, 2001), that is, those affected by sleep deprivation (Chee et al., 2008). By contrast, when the delay is short, the endogenous component of alertness may be preserved from sleep loss and the differential outcomes benefit is then more apparent. Future research might use neuroimaging techniques to better establish the neural mechanisms underlying differential outcomes benefits under sleep deprivation conditions.

4. Conclusions

Attention to sleep loss related problems has been growing in the last years. This interest stems from the fact that sleepiness and fatigue due to sleep loss or extended wakefulness leads to deterioration in performance, contributing to human error and accident (e.g., Barger et al., 2006). As a consequence, the identification of countermeasures that can reduce the risk of errors is necessary for many people who are required to work for extended period of time or to work through the night.

Here we showed that the differential outcomes procedure might be a useful technique that minimizes the effects of sleep loss on memory. Indeed, sleep-deprived participant showed DOP benefits (increase of accuracy), mainly when a short delay is used and the tonic alertness is not compromised by sleep loss.

Briefly, these novel findings can be of interest to researchers and clinicians exploring the effects of low-level arousal in daily life. Low arousal seems to be a typical condition not only observed in sleep-deprived people, but also in people suffering from psychiatric disorder, like ADHD or Alzheimer's disease (Festa-Martino, Ott, & Heindel, 2004). The differential outcomes procedure illustrated here might be of help to any of these populations.

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Author contributions

Conceived and designed the experiment: DM, VP, AFE, AC, LJF. Performed the experiment: DM, VP: Analyzed the data: DM, VP, AC, LJF. Wrote the paper: DM, VP, AFE, LJF.

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