Biological Psychology 104 (2015) 1–7

Contents lists available at ScienceDirect

Biological Psychology

journal homepage: www.elsevier.com/locate/biopsycho

Changes in attention to an emotional task after sleep deprivation: Neurophysiological and behavioral findings

Ramey Alfarra, Ana I. Fins, Isaac Chayo, Jaime L. Tartar*

Division of Social and Behavioral Sciences and Center for Psychological Studies, Nova Southeastern University, Ft. Lauderdale, FL, USA

ARTICLE INFO

Article history:
Received 18 April 2014
Accepted 4 November 2014
Available online 13 November 2014

Keywords:
Attention
Emotion
ERP
IAPS
LPP
Sleep deprivation

ABSTRACT

While sleep loss is shown to have widespread effects on cognitive processes, little is known about the impact of sleep loss on emotion processes. In order to expand on previous behavioral and physiological findings on how sleep loss influences emotion processing, we administered positive, negative, and neutral affective visual stimuli to individuals after one night of sleep deprivation while simultaneously acquiring EEG event related potential (ERP) data and recording affective behavioral responses. We compared these responses to a baseline testing session. We specifically looked at the late positive potential (LPP) component of the visual ERP as an established sensitive measure of attention to emotionally-charged visual stimuli. Our results show that after sleep deprivation, the LPP no longer discriminates between emotional and non-emotional pictures; after sleep deprivation the LPP amplitude was of similar amplitude for neutral, positive, and negative pictures. This effect was driven by an increase in the LPP to neutral pictures. Our behavioral measures show that, relative to baseline testing, emotional pictures are rated as less emotional following sleep deprivation with a concomitant reduction in emotional picture-induced anxiety. We did not observe any change in cortisol concentrations after sleep deprivation before or after emotional picture exposure, suggesting that the observed changes in emotion processing are independent of potential stress effects of sleep deprivation. Combined, our findings suggest that sleep loss interferes with proper allocation of attention resources during an emotional task.

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1. Introduction

Sleep loss has been shown to impact various aspects of cognitive processes (Killgore, 2010; Lim & Dinges, 2008; McCoy & Strecker, 2011). However, compared to the clear impairments in attention that have been shown after sleep loss, sleep loss has been found to have mixed results on emotion processing. In particular, some studies have shown decreased emotionality after sleep loss indicated by blunted affect (Talbot, McGlinchey, Kaplan, Dahl, & Harvey, 2010), impaired accurate recognition of human emotions (Van der Helm, Gujar, & Walker, 2010), decreased emotional expressiveness (Minkel, Htaik, Banks, & Dinges, 2011), and reduced emotional intelligence (Killgore et al., 2008). However, other studies have found increased emotionality after sleep loss indicated by exaggerated responses to negative stimuli (Tempesta et al., 2010), increased amygdala activity in response to emotionally negative stimuli (Yoo, Gujar, Hu, Jolesz, & Walker, 2007), and increased reward network activity in response to emotionally positive stimuli (Gujar, Yoo, Hu, & Walker, 2011). These differences may be due to dissimilar testing methodologies between studies (e.g. different types of self-report assessments of sleepiness and emotion, hemodynamic brain responses). An alternative explanation here is that the changes in emotion that occur after sleep loss are due to impairments in attention (Chuah et al., 2010; Sterpenich et al., 2009; Yoo et al., 2007). In other words, changes in tonic alertness due to sleep loss can impact emotion processing because emotional stimuli lose their ability to capture attention resources. Thus, in spite of an increase in amygdala activation after sleep deprivation, a decrease in attention to emotional stimuli would still result in a decrease in emotion processing and reactivity. In support of this theory, the increased amygdala activity seen after sleep loss is also associated with a decrease in amygdala-PFC functional connectivity, suggesting a reduction in emotion control processes after sleep deprivation (Yoo et al., 2007).

In order to expand on previous behavioral and physiological findings on the effect of sleep loss on emotion processing, we used behavioral measures (keyboard number pad ratings) combined with electroencephalographic (EEG) event related potentials (ERPs)

* Corresponding author at: Nova Southeastern University, Farquhar College of Arts and Sciences, Division of Social and Behavioral Sciences, 3301 College Avenue, Ft. Lauderdale, FL 33314, USA. Tel.: +1 954 262 8192.
E-mail address: tartar@nova.edu (J.L. Tartar).

http://dx.doi.org/10.1016/j.biopsycho.2014.11.001
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in response to non-emotional compared to emotional pictures after one night of sleep deprivation. We used positive and negative emotional pictures since these two picture categories have different effects on attention. Negative stimuli elicit more attention than positive stimuli and studies which have used ERPs to understand emotion processing show that negative pictures are more effective than positive pictures at capturing attention resources (Öhman & Mineka, 2001; Olofsson, Nordin, Sequeira, & Polich, 2008; Schupp, Öhman, et al., 2004).

ERPs were used since they can complement existing fMRI work due to their precise temporal resolution of the onset and duration of emotional processes and their great promise in explaining patterns of cortical reactions to emotional visual stimuli (Olofsson et al., 2008). The late positive potential (LPP) component of the visual ERP is specifically established as a sensitive measure of attention to emotionally charged visual stimuli (Cuthbert, Schupp, Bradley, Birbaumer, & Lang, 2000; Keil et al., 2002; Olofsson & Polich, 2007). Induction of the LPP is thought to serve as a neurobiological correlate of motivated attention to stimuli of adaptive significance (sex, death, etc.). In other words, because these stimuli are inherently arousing, they require the preferential allocation of limited attention resources (Lang, Simons, & Balaban, 1997). In support of this idea, evidence suggests that the LPP is involved in memory formation for emotional events (Dolcos & Cabeza, 2002; Palomba, Angrilli, & Mini, 1997). Emotional modulation of the LPP is highly stable – it has been shown to be consistent over time within individuals and is not sensitive to habituation (Codispoti, Ferrari, & Bradley, 2006; Hajcak, MacNamara, & Olvet, 2010).

The aim of the current study was to investigate the influence of 24 h of sleep deprivation on emotion processing. To that end, we measured behavioral and ERP LPP measures of emotion processing during a baseline morning testing session and compared those responses to a morning testing session following 24 h of sleep deprivation. The current study directly tested the idea that sleep deprivation interferes with the allocation of attentional resources to an emotional task. The emotional task measures included the LPP ERP amplitude with concomitant behavioral ratings to emotionally positive, negative, and neutral pictures. In order to complement our emotion measures, we also assessed anxiety during baseline and sleep deprivation sessions both before and after emotional picture exposure since sleep fragmentation has been shown to have anxiolytic effects in rats (Tartar et al., 2009). Finally, we measured salivary cortisol levels in order to examine the extent to which any observed changes in emotion processing could be related to sleep deprivation-induced changes in morning cortisol levels. Since we observed robust changes in the LPP after sleep deprivation, we followed up these findings with a control ERP experiment to ensure that any deviations from baseline were a result of sleep deprivation as opposed to habituation to the emotion task.

2. Methods

2.1. Participants

Participants were recruited via flyers posted around campus or through a university research participation website. A total of twenty-two healthy right-handed participants with normal or corrected-to-normal vision were recruited for this study. Twelve participants were tested in the first experiment which directly assessed the effects of sleep deprivation relative to a baseline testing condition. This experiment consisted of a baseline testing session and one night of sleep deprivation two days later followed by a second ERP testing session. They also underwent sleep monitoring as well as anxiety and stress assessment. One participant was removed after the baseline testing session because the baseline testing session showed no difference in the LPP between emotional and non-emotional picture categories. One additional participant did not return after baseline testing, leaving ten participants in the sleep deprivation experiment (5 males, mean age = 23, SD = 3.97, range 19–30). Ten participants underwent only the ERP testing portion of the experiment with no sleep deprivation (4 males, mean age = 21, SD = 2.80, range = 18–27) in two sessions scheduled two days apart. These participants were tested as a follow-up experiment to explicitly ensure that the LPP results observed in the sleep deprivation group were not due to habituation effects. Since this group did not undergo sleep deprivation, there was no reason to monitor their sleep or test them for sleep deprivation-induced changes in morning cortisol or anxiety. Every participant was first administered the Epworth Sleepiness Scale (ESS) in order to pre-screen for potential sleep disorders or conditions associated with excessive daytime sleepiness (enrollment criterion was a score of less than 10). No participants were excluded based on ESS score criterion. In addition, all study participants were asked to refrain from caffeine use 24 h prior to, and during, study participation. The recruitment and testing procedures were approved by and carried out according to a protocol submitted to the Nova Southeastern University (NSU) Institutional Review Board. Participants in the sleep deprivation experiment were compensated for their time with a $100 gift card to a local store and participants in the control experiment were compensated for their time with either a $10 gift card to a local store or research participation credit as part of an Introduction to Psychology course requirement.

2.2. Stimuli and design

Visual ERPs were elicited from participants while they viewed pictures selected from the International Affective Picture System (IAPS) (Lang, Bradley, & Cuthbert, 1997). Picture presentation and timing were controlled through the use of Presentation software (Neurobehavioral Systems, LLC). There were 105 trials and each trial began with a 400 ms randomized presentation of either a negative (n = 35), neutral (n = 35) or positive (n = 35) independent IAPS pictures. The 400 ms picture on-time was chosen since even briefly presented pictures capture attention resources, but also has the advantage of better evoking both early posterior negativity (EPN) and LPP components (Schupp, Junghöfer, Weike, & Hamm, 2004). A central fixation point was present in the center of the screen throughout the experiment. Following the picture presentation, a black screen was on for the rest of the trial (4000 ms) during which time the participants were instructed to categorize the picture, via a keyboard button press, before the next trial began. All pictures were presented on a 23-in. LCD monitor with a vertical refresh rate of 60 Hz.

Independent picture sets were used for the first and the second testing session and the order was counter-balanced across participants. The IAPS normative ratings (Lang et al., 1999) were used to select the neutral, negative, and positive pictures. The average valence for each picture category (neutral, negative, and positive) was matched in the two picture sets. The average picture valences were as follows: neutral pictures set 1 mean = 5.11, SD = 0.32, neutral pictures set 2 mean = 5.09, SD = 0.26, negative pictures set 1 mean = 2.35, SD = 0.51, negative pictures set 2 mean = 2.35, SD = 0.62, positive pictures set 1 mean = 7.51, SD = 0.47, positive pictures set 2 mean = 7.47, SD = 0.46.[1] Image sets were also matched for arousal ratings within valence category. Negative and positive images were significantly more arousing than neutral images. However, the negative images were also significantly more arousing than the positive images. The average picture arousal levels were as follows: neutral pictures set 1 mean = 3.60, SD = 0.72, neutral pictures set 2 mean = 3.35, SD = 0.84, negative pictures set 1 mean = 5.89, SD = 0.81, negative pictures set 2 mean = 5.93, SD = 0.70, positive pictures set 1 mean = 4.95, SD = 0.76, positive pictures set 2 mean = 5.01, SD = 0.93. Accordingly, the central selection criterion here was along the dimension of picture valence and our operational definition of "emotional" refers strictly to the pleasantness or unpleasantness of the pictures.

2.3. Procedure

All EEG testing occurred between 7:00 and 9:00 a.m. and included one baseline testing session and one sleep deprivation or ERP/picture control testing session two days later. All participants first filled out a brief demographics form during the first testing session. The participants were seated in a dimly lit sound-attenuated room. Participants were then fitted with an electrode cap and EOG electrodes. The

[1] IAPS picture directory reference numbers for the images used in the present study. Neutral picture set 1: 6910, 7002, 7009, 7014, 7019, 7030, 7033, 7036, 7040, 7044, 7052, 7056, 7057, 7061, 7080, 7096, 7130, 7161, 7180, 7184, 7188, 7205, 7207, 7224, 7237, 7247, 7249, 7287, 7354, 7487, 7546, 7500, 7560, 8060, and 8312. Neutral picture set 2: 7000, 7003, 7010, 7017, 7020, 7025, 7031, 7034, 7037, 7041, 7045, 7053, 7058, 7062, 7081, 7100, 7140, 7160, 7170, 7182, 7185, 7187, 7190, 7211, 7235, 7242, 7255, 7290, 7365, 7493, 7506, 7547, 7820, 8065, and 8232. Negative picture set 1: 1052, 1201, 1271, 2053, 2205, 2276, 2375.1, 2683, 2799, 2800, 3000, 3001, 3005.1, 3010, 3017, 3030, 3060, 3064, 3230, 3400, 6021, 6212, 6260, 6312, 6510, 6530, 6831, 9181, 9290, 9491, 9520, 9561, 9902, 9903, and 9927. Negative picture set 2: 1051, 1202, 1274, 2095, 2455, 2688, 2730, 2811, 2900, 3015, 3016, 3053, 3062, 3063, 3261, 3266, 3301, 3350, 3500, 3530, 6022, 6213, 6250, 6311, 6415, 6550, 6834, 9075, 9184, 9291, 9530, 9600, 9901, 9904, and 9922. Positive picture set 1: 1440, 1463, 1500, 1721, 1750, 1999, 2045, 2058, 2080, 2154, 2170, 2260, 2314, 2341, 2360, 2398, 2540, 4007, 4533, 4597, 4610, 4643, 4676, 5621, 5825, 5831, 5982, 7330, 7350, 7492, 7580, 8170, 8420, 8499, and 8540. Positive picture set 2: 1441, 1610, 1620, 1811, 2035, 2050, 2070, 2091, 2160, 2209, 2224, 2274, 2332, 2345, 2395, 2550, 2650, 4090, 4535, 4599, 4614, 4650, 4668, 5480, 5594, 5700, 5829, 5833, 7200, 7400, 7502, 8185, 8470, 8501, and 8510.

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