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RESEARCH ARTICLE

Effects of sleep loss on emotion recognition: a dissociation between face and word stimuli

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Abstract Short-term sleep deprivation, or extended wakefulness, adversely affects cognitive functions and behavior. However, scarce research has addressed the effects of sleep deprivation (SD) on emotional processing. In this study, we investigated the impact of reduced vigilance due to moderate sleep deprivation on the ability to recognize emotional expressions of faces and emotional content of words. Participants remained awake for 24 h and performed the tasks in two sessions, one in which they were not affected by sleep loss (baseline; BSL), and other affected by SD, according to a counterbalanced sequence. Tasks were carried out twice at 10:00 and 4:00 am, or at 12:00 and 6:00 am. In both tasks, participants had to respond to the emotional valence of the target stimulus: negative, positive, or neutral. The results showed that in the word task, sleep deprivation impaired recognition irrespective of the emotional valence of words. However, sleep deprivation impaired recognition of emotional face expressions mainly when they showed a neutral expression. Emotional face expressions were less affected by the sleep loss, but positive faces were more resistant than negative faces to the detrimental effect of sleep deprivation. The differential effects of sleep deprivation on recognition of the different emotional stimuli are indicative of emotional facial expressions being stronger emotional stimuli than emotional laden words. This dissociation may be attributed to the more automatic sensory encoding of emotional facial content.

Keywords Sleep loss · Nighttime · Emotion · Mood · Face recognition · Word recognition · Choice reaction times

Introduction

Short-term sleep deprivation, due to nighttime work during a 24-h period of sustained wakefulness, adversely affects cognitive functions and behavior. Deteriorate effects have been shown to involve vigilance, executive attention, working memory, language, divergent thinking, and creativity (Goel et al. 2009; Lim and Dinges 2010; Martella et al. 2011). However, despite substantial research has been conducted on the interaction between sleep and cognition, the impact of vigilance drop, due to sleep loss, on basic processes related to emotional regulation and perception has surprisingly received scarce research attention (Walker and van der Helm 2009). Sleep loss has been shown to adversely affect mood (Rosen et al. 2006; Scott et al. 2006), and it usually raises subjective complaints of emotion-related disturbances such as irritability and/or behavioral volatility (Dinges et al. 1997; Zohar et al. 2005). In addition, the high incidence of sleep abnormalities in most psychiatric and neurological mood-related disorders (Riemann 2007) suggests a close relationship between sleep and emotional reactions (Walker and van der Helm 2009). Beside the evidence, little is known about the effects of vigilance drop, due to sleep loss, on recognition of emotionally laden information.

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Research on sleep shows that there is several ways to induce sleep deprivation. One rather ecological method is to ask participants to keep awake beyond their usual time of sleep onset. It has the advantage of being a method that simulates some people's real situations, above all those that require them to extend wakefulness for at least 24 h (i.e., a physician in an intensive care unit, a fireman in disaster evacuation, and a pilot in long-haul flights) (Barger et al. 2006; Tsai et al. 2005). For instance, firemen usually work for 8 h a day but, in certain circumstances, they may be required to work for up to 24 consecutive hours or even more. When participants are asked to keep awake for such extended period, their performance might be affected by factors such as sleep loss per se, circadian cycle variation (i.e., nighttime hours; Dijk and Czeisler 1995; Lavie 2001), or operational fatigue. The crucial issue is to determine how performance is modulated by reduced vigilance when people are drowsy rather than to establish the specific contribution of each factor (Barger et al. 2006; Casagrande 2002; Tsai et al. 2005). Importantly, we have previously demonstrated that the proposed method to induce sleep deprivation has probed useful to produce a significant reduction in vigilance due to sleep loss and nighttime hours (Casagrande et al. 2006; Marotta et al. 2014; Martella et al. 2011).

Regarding the relations between sleep and emotion, Dahl and Lewin (2002) proposed an important neuroanatomical model in which sleep loss leads to deficits in emotional regulation through its effects on the prefrontal cortex, a region particularly implicated in inhibitory control of negative emotions (see Ochsner and Gross 2005 for review). Consistent with Dahl and Lewin's theory (Dahl and Lewin 2002), Yoo et al. (2007) found that sleep-deprived people exhibited a remarkable increase in activation (above 60 %) and as far as three times more volume in the amygdala, relative to the control group, in response to picture stimuli bearing increasingly negative affect. In addition, following sleep deprivation, both increase in amygdala activation and reduced functional connectivity between the amygdala and prefrontal cognitive control regions are associated with greater distraction by negative stimuli during a working memory task (Chuah et al. 2010). Franzen et al. (2009) have also reported amplified reactions to negative emotional information during sleep deprivation by using a pupillography technique. Participants of the sleep-deprived group showed greater pupillary dilation in response to negative compared to positive or neutral pictures than participants in the control group. Sleep loss has also been associated with increased impulsivity to negative stimuli when a Go/Nogo task was used (Anderson and Platten 2011). Sleep-deprived individuals not only exhibited more difficulties to inhibit the response, but also faster incorrect responses. Taken together, these findings suggest that sleep loss detrimentally amplified the human emotional brain system in response to negative aversive stimuli up to the point of impair performance.

However, sleep loss might affect *tout court* the emotional processing, involving both negative and positive emotional stimuli. Accordingly, Gujar et al. (2011) showed that sleep loss changed the dynamics of brain and behavioral reactivity to rewarding positive pictures, suggesting a bidirectional affective imbalance-associated deprivation. Concretely, sleep deprivation produced amplified reactivity in responses to positive stimuli throughout midbrain, striatal, limbic, and visual regions. An alternative view is to assume that effects of sleep loss on emotional processing are strength-dependent rather than valence-dependent. In line with this, van der Helm et al. (2010) found that when participants were required to make emotional strength ratings of human facial expressions, sleep deprivation selectively impaired the accuracy of judgments when moderate anger and happy (although not sad) expressions were presented. Interestingly, impairment in judgments emerged only in responses to emotionally ambiguous facial expressions, but neither neutral nor strong emotional facial expressions seemed to be affected by one night of sleep deprivation. These findings suggest that it is the threshold for emotion recognition what might be affected by sleep loss, that is, the intensity of facial emotional expressions required to activate the respective emotional networks may be greater under conditions of sleep deprivation, whereas the basic aspects of facial emotional expression perception might be spared (Schroder 2010). Some studies revealed that strong emotional stimuli (van der Helm et al. 2010) or negative emotional stimuli seem to be more resistant to the deleterious effect of sleep deprivation (Anderson and Platten 2011; Cote et al. 2013; Franzen et al. 2009). Thus, resistance to sleep loss deleterious effects may foster appropriate reactions toward negative emotional stimulation even under less favored conditions (Chuah et al. 2010; Gujar et al. 2011).

In the present study, we used an extended wakefulness paradigm to further exploring the effects of sleep deprivation on emotional recognition as a function of emotional valence (positive, negative, and neutral) and type of stimulus (faces and words). Regarding valence, we expected recognition of faces showing negative expressions to be unaffected, or less affected, by sleep loss compared with faces showing neutral facial expressions (Anderson and Platten 2011; Chuah et al. 2010; Franzen et al. 2009; Yoo et al. 2007). However, if sleep loss affects *tout court* emotion recognition (Gujar et al. 2011), resistance to the deleterious effects of sleep deprivation should extend to positive emotional face expressions as well. Regarding the type of stimuli, we expected emotional face expressions to be more resistant to the deleterious effects of sleep deprivation than emotionally laden words, as emotional content of faces seems to be processed more automatically than emotional content of words (Fruhholz et al. 2011; Rellecke et al. 2011).

Materials and methods

Participants

Eighteen healthy volunteers (3 males, 15 females; mean age: 24.28 ± 2.30) participated in the study after signing the informed consent form. All participants were right-handed according to the Hand Preference Index >0.85, as assessed by the Lateral Preference Questionnaire (Salmaso and Longoni 1985). They were all naïve to the purpose of the experiment, and all reported normal or corrected-to-normal vision. To participate in the experiment, participants should present no sleep, medical, or psychiatric disorders, being non-smokers, drug-free, and report both 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). The experiment was conducted according to the ethical standards of the Declaration of Helsinki 1964 and was approved by the local ethics committee.

Apparatus

The stimuli were presented on a 21-inch color VGA monitor (HP Hewlett Packard 71). An IBM compatible PC running E-Prime software controlled the stimulus presentation, timing operations, and data collection. Responses were collected through the computer keyboard.

Stimuli

Two types of stimuli were used in the experiment, faces and words.

Face stimuli

Four professional actors (2 females) were asked to express one neutral, four negative (anger, fear, disgust, and sadness), and four positive (calmness, hilarity, happiness, and surprise) emotions. All pictures were measured 890 × 1,300 pixels with a resolution of 72 dpi. and 2 × 3 cm on the screen.

Word stimuli

We used four Italian negative words: "paura," "rabbia," "disgusto," and "tristezza" (in English "anger," "fear," "disgust," and "sadness," respectively); four Italian positive words: "calma," "sorpresa," "ilarità," and "felicità" (in English "calmness," "hilarity," "happiness," and "surprise," respectively); and four Italian neutral words: "marca," "casella," "capitale," and "anteprima" (in English "brand," "check box," "capital," and "preview," respectively). Neutral words matched negative and positive words in both length and frequency of usage in the Italian language according to the De Mauro et al. (1993) frequency dictionary. An Arial 12 font was used, and words had 5–9 characters. Words were presented vertically to avoid any influence of their length and alternated uppercase and lowercase characters to hinder a global-based strategy to recognize them.

Valence and arousal ratings

Previous to the start of the experiment, 22 university students who did not participate in the proper experiment were required to rate independently both the emotional valence and the arousal level of all the stimuli. They were told to use a scale ranging from 0 to 9 where 0 = lowest negative valence/arousal, and 9 = highest positive valence/arousal. The scale was taken from the International Affective Picture System (IAPS; Lang et al. 2008). Each stimulus was presented on the screen for 15 s. The mean valence ratings for faces were 6.74 for positive, 5.04 for neutral, and 3.02 for negative, and for words were 6.12 for positive, 4.84 for neutral, and 3.72 for negative. The mean arousal levels for faces were 4.77 for positive, 3.94 for neutral, and 5.62 for negative, and for words were 4.22 for positive, 3.23 for neutral, and 4.85 for negative. We conducted two repeated measures ANOVAs, one for the valence ratings and the other for the arousal ratings, with *Type of stimulus* (faces and words) and *Valence* (positive, neutral, and negative) as within-participants factors. The analysis with valence ratings showed a significant effect of both *Type of stimulus* ($F1,21 = 12.72$; $p < 0.01$) and *Valence* ($F2,42 = 109.57$; $p < 0.00001$). Ratings were higher for faces than for words (4.93 vs. 4.89). Also negative faces were rated more negative than negative words (difference of 0.70 points), and positive faces more positive than positive words (difference of 0.62 points), although those differences were not captured by a significant interaction between the two factors. The three valences differed significantly in both faces and words. The analysis with arousal ratings showed significant effects of both *Type of stimulus* ($F1,21 = 35.33$; $p < 0.00001$) and *Valence* ($F2,42 = 12.61$; $p < 0.0001$). Faces were more arousing than words (4.78 vs. 4.1), and emotional stimuli produced more arousal levels than neutral stimuli (4.87 vs. 3.59; $p < 0.05$). There were no significant differences between the positive and negative stimuli ($p > 0.05$).

Experimental task

Participants were seated in a dark and quite room 60 cm directly in front of the screen, and their heads were held steady with the help of a chin/head rest. Figure 1 shows the

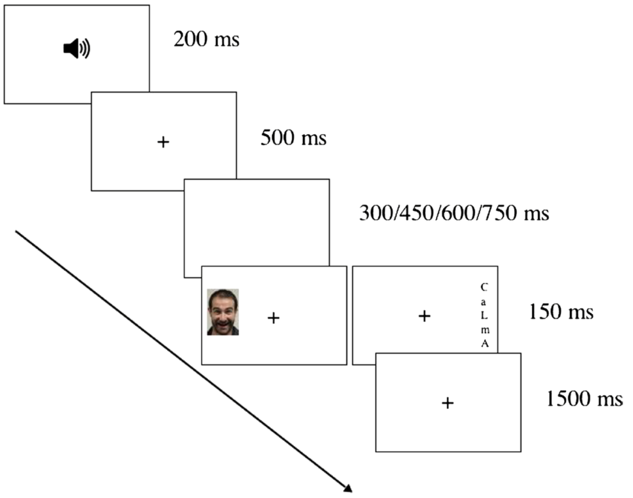


Fig. 1 Sequence of events of a trial in the face recognition task (*left side*) and the word recognition task (*right side*)

sequence of events for each trial. First, an acoustic signal was presented for 200 ms, followed by the fixation point (a cross) with a duration of 500 ms. After a variable interval of 300, 450, 600, or 750 ms, the target stimulus was presented just for 150 ms. The target was randomly presented 6 degree of visual angle to the left or right of the fixation point. Participants were required to keep their eyes on the fixation point and to respond to the valence of the target by pressing one of the three horizontally placed keys as fast and accurately as possible. The key "I" was used for positive targets, the key "K" for negative targets, and the key "M" for neutral targets. In half the trials, the target was presented to the left, and to the right in the other half. Also, in half the trials, participants used their right hand to respond and their left hand in the other half. The order of the starting hand was counterbalanced. Participants were told to judge the valence of the target as quickly and accurately as possible within a time limit of 1,500 ms. Just before starting with the experimental trials, participants received 60 training trials (the practice block). A rerun procedure was arranged that consisted of repeating trials with errors or response latencies either shorter than 100 ms or longer than 1,000 ms. If a participant did not reach 75 % accuracy, he/she was asked to repeat the practice block until the accuracy/latency criterion was met. Participants then performed 8 blocks of 132 trials each (in 12 trials, the target was not presented and served as catch trials). The experiment lasted about 55 min during which the participants were allowed to take a break.

Mood

For measuring current participants' mood, we used one-dimensional visual analogue scales (VAS; Casagrande et al. 1997), which required each participant to respond to the question: "How do you feel right now with respect to the adjective _____?". The following adjectives were used: sleepy, tired, energetic, concentrated, calm, tense, happy, sad, and irritable. For each adjective, participants responded by making a stroke with a pen on a 100-mm-long line. The stroke should reflect the intensity of the self-evaluation. Each line was anchored at one end with "not at all" and at the other end with "very much."

Body temperature

Additionally, the peripheral body temperature (BT), strictly closed to the wake–sleep cycle, was hourly measured using an oral thermometer to evaluate the circadian rhythmicity of the participants.

General procedure

In the first day, participants came individually to the laboratory and were subjected to a brief interview aimed at obtaining information on sleep duration and schedule, the presence of any disease, and the use of drugs. They also completed the Lateral Preference Questionnaire (Salmaso and Longoni 1985). Once the participant was considered eligible for the research, he/she was given detailed information about the procedure. Participants signed the informed consent to participate in the research, and they then performed the training block until they met with the latency/accuracy requirements. At the end of this session, participants were reminded to maintain regular sleeping hours throughout the duration of the study, and were given a sleep log that they had to fill in immediately after awakening (no more than 20 min) for a week. Compliance to a regular sleep schedule was verified by checking the sleep log.

About 1 week later, participants came back to the laboratory at 8.30 am for the experimental sessions, during which they had to be awake for 24 h. In order to control for carry over effects, the order of the two sessions (SD and BSL) were counterbalanced across participants as it follows. For those participants who performed session BSL first, the schedule was as mentioned above: both sessions took place between 10.00 am of the arrival day and 6.00 am of the following day. For those participants who performed session SD first, session BSL was scheduled 3 days later. In this case, we maintained the same wakefulness schedule, that is, the participant came to the laboratory at 8.30 am and kept awake for 24 h. Then, he/she performed the first session (SD) at either 4.00 am or 6.00 am (depending on the task) of the following day. The second session (BSL) was performed 3 days later at either 10.00 am or 12.00 am (depending on the task) of the arrival day. The tasks were performed individually in a sound-attenuated air-conditioned room. The VASs and body temperature were recorded hourly. The participants were allowed two breaks, one for lunch (about 1.00 pm) and one for dinner (about 8.00 pm), during the 24-h. period. During the time between the experimental sessions, participants were not allowed to drink or eat anything containing caffeine (e.g., coffee, tea, and chocolate). The experimenters continuously monitored the participants in order to avoid any naps. The environmental temperature was set to 25 °C. The laboratory was constantly illuminated with artificial light of 500 lux; the cabin where the experiment was conducted had illumination of about 20 lux.

Results

Mood

The distance of the mark from the left end of the line for all adjectives was computed for the mood analyses. This method yields two measures of mood: energetic activation (EA) and affective tone (AT). The measures were computed by applying the following formulas: EA = (energetic + concentrated + 200) − (sleepy + tired); and AT = (calm + happy + 300) − (sad + irritable + tense). In one first analysis, a repeated measures ANOVA was performed on both EA and AT, with *Hour of day* as the within-participants factor. We found significant effects for both EA ($F23{,}391 = 23.33$; $p < 0.00001$; $\eta^2 = 0.55$; Greenhouse–Geisser correction: Epsilon = 0.36; degrees of freedom: 8.2,156.4; $p < 0.00001$), and AT ($F23{,}391 = 6.04$; $p < 0.00001$; $\eta^2 = 0.24$; Greenhouse–Geisser correction: Epsilon = 0.22; degrees of freedom: 5,95.9; $p = 0.00006$) (Fig. 2). Trend analyses revealed a significant linear trend for both EA ($F1{,}17 = 136.73$; $p < 0.00001$; $\eta^2 = 0.88$) and AT ($F1{,}17 = 20.32$; $p < 0.001$; $\eta^2 = 0.52$). In one additional analysis, we assessed whether the two tasks (FR and WR) differed significantly on both mood measures at the two time windows that were chosen to perform each task. Repeated measures ANOVAs with *Session* (BSL vs. SD) and *Task Time* (FR time vs. WR time) as within-participants factors were carried out on both EA and AT scores. For energetic activation scores, we found significant effects of *Session* ($F1{,}17 = 116.08$; $p < 0.00001$; $\eta^2 = 0.86$) and *Task Time* ($F1{,}17 = 5.75$; $p < 0.05$; $\eta^2 = 0.23$). EA scores were higher for session BSL than for session SD (256 vs. 111), and higher in the time window corresponding to the FR task (196) than to the WR task (170). The interaction between the two factors was not significant ($F < 1$). For the affective tone scores, we also observed significant effects of *Session* ($F1{,}17 = 6.57$; $p < 0.05$; $\eta^2 = 0.26$) and *Task Time* ($F1{,}17 = 6.42$; $p < 0.05$; $\eta^2 = 0.25$). As with EA scores, AT scores were higher for session BSL than for session SD (326 vs. 306), and higher in the time window corresponding to the FR task (333) than to the WR task (298). The interaction between the two factors was not significant either ($F < 1$).

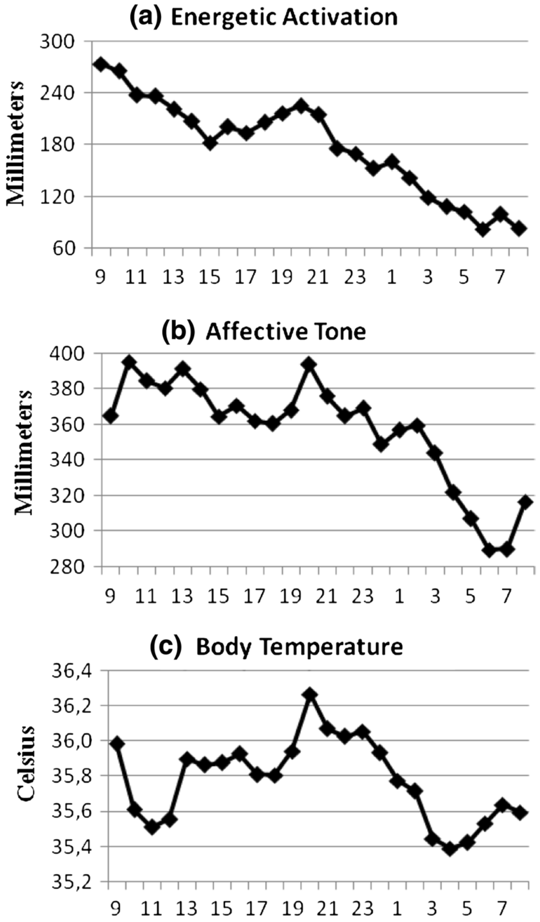


Fig. 2 Mean measures of **a** energetic activation, **b** affective tone, and **c** body temperature through the 24 h of sustained wakefulness

Body temperature

The effect of *Hour* of the day on body temperature probed significant ($F23{,}437 = 7.72$; $p < 0.00001$; $\eta^2 = 0.29$; Greenhouse–Geisser correction: $\varepsilon = 0.30$; degrees of freedom: 6.9,131.1; $p = 0.00001$). This result showed the typical circadian trend closed to wake/sleep cycle (Fig. 2).

Reaction times

Only reaction times (RTs) for correct responses that were longer than 200 ms and shorter than the mean RT + 2SD entered into the statistical analyses. According to that trimming procedure, 5.5 % of trials for the FR task and 4.8 % of trials for the WR task were excluded from the statistical analyses. Table 1 shows the mean (±SD) RTs for each

Table 1 Mean (±SD) RTs of corrected responses for baseline and sleep deprivation conditions in face and word recognition tasks

	Face						Word					
	Baseline			Sleep deprivation			Baseline			Sleep deprivation		
	Mean	SD	E	Mean	SD	E	Mean	SD	E	Mean	SD	E
NEG	854.10	85.39	20.13	888.17	87.89	20.72	793.19	95.52	22.51	869.22	97.65	23.02
NEU	871.32	71.17	16.78	936.43	84.94	20.02	842.52	83.99	19.80	928.05	102.98	24.27
POS	804.14	102.38	24.13	820.34	91.41	21.55	851.90	106.89	25.20	941.31	116.22	27.39

SD standard deviation, *E* percentage of errors

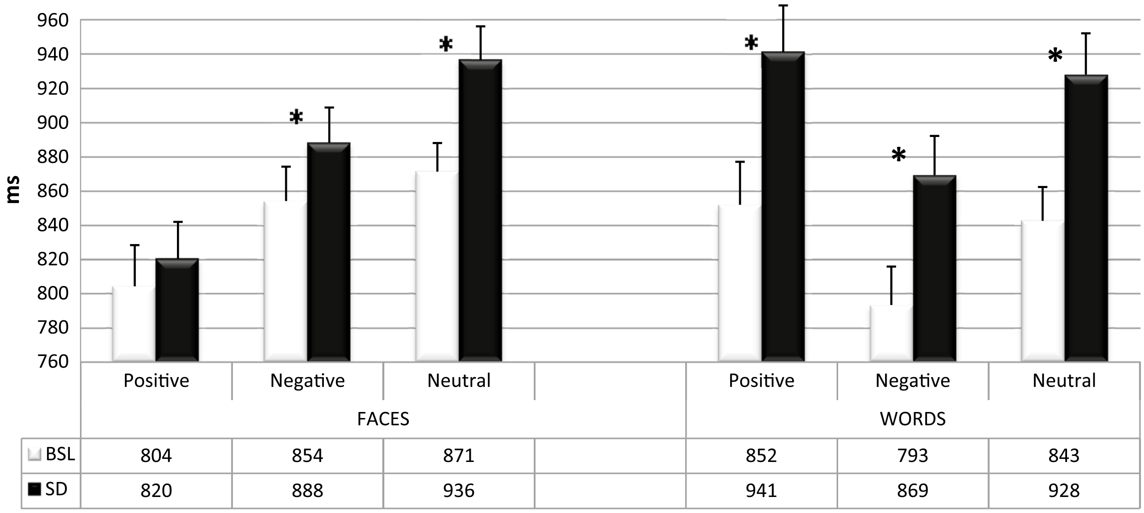


Fig. 3 Mean RTs for positive, negative, and neutral emotional valences in both face recognition (*left side*) words recognition (*right side*) tasks during BSL and SD sessions. *Error bars* represent the standard error of each condition

experimental condition for both BSL and SD sessions. For each task, a repeated measure ANOVA was carried out with *Session* (BSL, SD) and *Valence* (positive, negative, neutral) as the within-participants factors.

Face stimuli

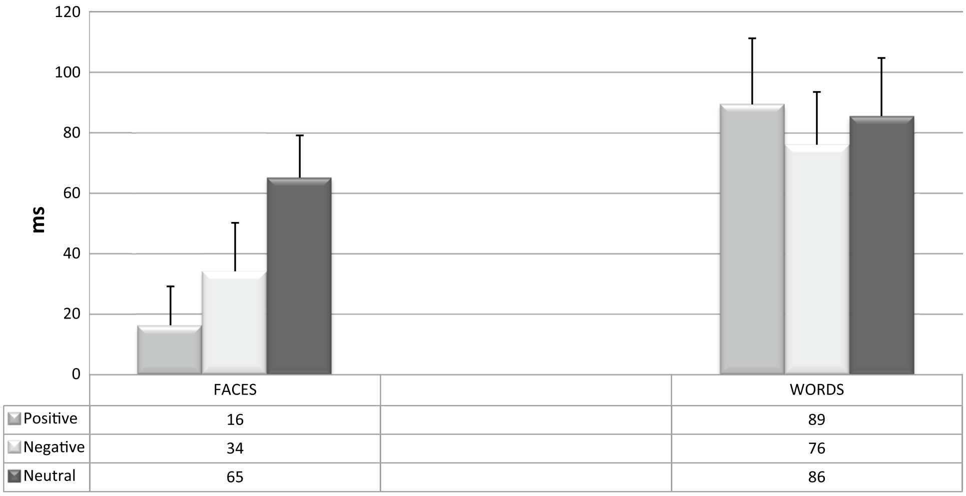
There were significant effects of *Session* ($F1,17 = 14.35$; $p < 0.001$; $\eta^2 = 0.46$) and *Valence* ($F2,34 = 21.26$; $p < 0.0001$; $\eta^2 = 0.56$). RTs in session SD were slower than in session BSL (882 vs. 843 ms). Participants recognized positive facial expressions (812 ms) faster than both negative (871 ms) ($F1,17 = 14.88$; $p < 0.001$; $\eta^2 = 0.47$) and neutral facial expressions (904 ms) ($F1,17 = 38.11$; $p < 0.00001$; $\eta^2 = 0.69$). Negative expressions were also recognized faster than neutral ones ($F1,17 = 6.91$; $p < 0.05$; $\eta^2 = 0.29$). The *Session* × *Valence* interaction was also significant ($F2,34 = 3.93$; $p < 0.005$; $\eta^2 = 0.19$). The analysis of the interaction showed that RTs in session SD were slower than in session BSL for both neutral facial expressions (871 vs. 936 ms; $F1,17 = 21.59$; $p < 0.0005$; $\eta^2 = 0.56$) and negative facial expressions (854 vs. 888 ms; $F1,17 = 4.49$; $p < 0.05$; $\eta^2 = 0.21$). However, there were no differences between the two sessions for the positive facial expressions (804 vs. 820 ms; $F1,17 = 1.58$; $p = 0.23$; $\eta^2 = 0.09$) (see left graph of Fig. 3).

Word Stimuli

There were significant effects of *Session* ($F1,17 = 20.05$; $p < 0.0001$; $\eta^2 = 0.54$) and *Valence* ($F2,34 = 26.27$; $p < 0.0001$; $\eta^2 = 0.61$). RTs were slower in session SD than in session BSL (913 vs. 829 ms). Participants recognized negative words (831 ms) faster than both neutral (885 ms) ($F1,17 = 34.88$; $p < 0.0001$; $\eta^2 = 0.67$) and positive words (897 ms) ($F1,17 = 55.85$; $p < 0.00001$; $\eta^2 = 0.77$), but there were not differences between neutral and positive words ($F1,17 = 1.08$; $p = 0.31$; $\eta^2 = 0.06$). The interaction *Session* × *Valence* was not significant ($F < 1$) (see right graph of Fig. 3).

Finally, since arousal (i.e., EA) and mood (i.e., AT) were lower when participants performed the WR task compared with the FR task during the night, ANCOVAs were performed with *Session* and *Valence* as the within-participants

Fig. 4 Mean SDE (RT in SD session–RT in BSL session) in the face and word recognition tasks. *Error bars* represent the standard error of each condition



factors, and differences in both EA and AT observed between 4:00 and 6:00 am as covariates. The results were the same as with the ANOVAs.

The sleep deprivation effect

Additional analyses were carried out to further explore the differential effect of sleep deprivation in the FR task compared with the WR task. A sleep deprivation effect (SDE) was computed as the difference in reaction times between the two sessions (SDE = RT in session SD − RT in session BSL). Then, we performed a *Task* (FR, WR) × *Valence* (positive, negative, and neutral) repeated measures ANOVA with SDE as the dependent variable. There was a significant main effect of *Task* ($F1,17 = 5.18$; $p < 0.05$; partial $\eta^2 = 0.23$). The SDE was smaller in the FR task than in the WR task (38 vs. 83 ms). The main effect of *Valence* was not significant ($F2,34 = 2.92$; $p > 0.05$; $\eta^2 = 0.15$), but it interacted significantly with *Task* ($F2,34 = 3.36$; $p < 0.05$; $\eta^2 = 0.17$). The interaction analysis showed no modulation of *Valence* on the SDE in the WR task ($p > 0.05$ for all comparisons). However, the SDE for the FR task was larger for neutral (65 ms) than for both negative (34 ms; $p < 0.05$) and positive (16 ms; $p < 0.01$) faces in the FR task. The SDE was not significantly different for negative and positive faces ($p = 0.23$). These results are illustrated in Fig. 4.

Percentage of errors

Face stimuli

There was a significant main effect of *Session* ($F1,17 = 12.17$; $p < 0.003$; $\eta^2 = 0.42$), with higher percentage of errors in session SD than in session BSL (29.70 vs. 23.63 %). The main effect of *Valence* was not significant ($F2,34 = 2.41$; $p = 0.10$), but it interacted significantly with *Session* ($F2,34 = 8.40$; $p < 0.005$; $\eta^2 = 0.33$). The interaction analysis showed that session SD produced higher percentage of errors than session BSL for both positive ($F1,17 = 15.15$; $p < 0.002$; $\eta^2 = 0.47$) and neutral facial expressions ($F1,17 = 12.25$; $p < 0.003$; $\eta^2 = 0.42$), but there were no differences for negative facial expressions ($F < 1$) (see left graph of Fig. 5).

Word stimuli

There were significant main effects of both *Session* ($F1,17 = 10.88$; $p < 0.005$; $\eta^2 = 0.39$) and *Valence* ($F2,34 = 11.90$; $p < 0.0002$; $\eta^2 = 0.41$). Percentage of errors was higher in session SD than in session BSL (10.07 vs. 5.09 %), and for positive words (11.64 %) than for both negative (5.14 %) ($F1.17 = 15.47$; $p < 0.001$; $\eta^2 = 0.48$) and neutral (5.97 %) ($F1.17 = 10.72$; $p < 0.005$; $\eta^2 = 0.39$) words. Percentage of errors for negative and neutral words did not differ significantly ($F1,17 = 1.20$; $p = 0.29$). The interaction *Session* × *Valence* was also significant ($F2,34 = 4.46$; $p < 0.05$; $\eta^2 = 0.21$). The analysis of the interaction showed that the difference in error percentage between session SD and session BSL was significant for the three types of emotional words, but it was larger for positive (8.16 %), than for both negative (2.61 %) and neutral (4.17 %) words (see right graph of Fig. 5).

Discussion

A main feature of the extended wakefulness paradigm is that it has probed suitable to produce reduced vigilance as a consequence of both nighttime and moderate sleep loss. The paradigm recreates in the laboratory a condition that matches that of many real-life situations, such as when people's duties require them to sustain wakefulness

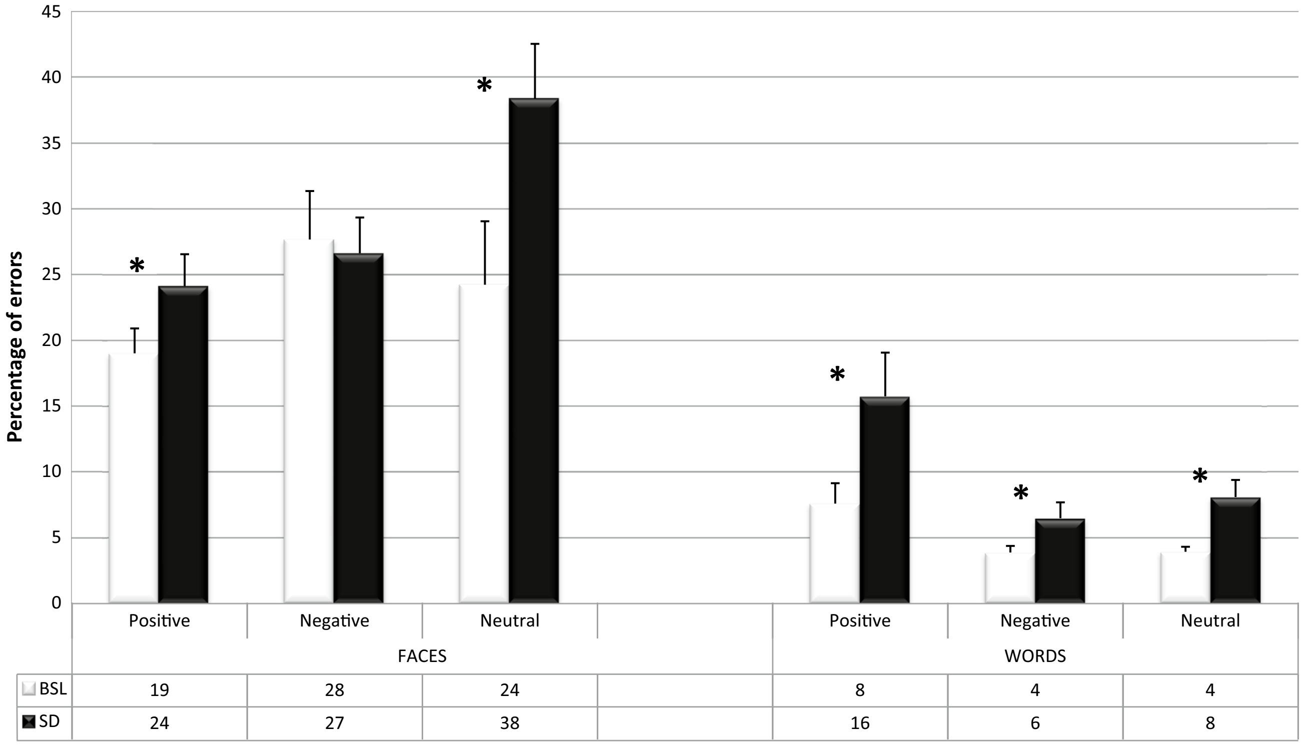


Fig. 5 Mean percentage of errors for positive, negative, and neutral emotional valences in both face recognition (*left side*) words recognition (*right side*) tasks during BSL and SD sessions. *Error bars* represent the standard error of each condition

for 24 h or work at night (Casagrande et al. 2006; Martella et al. 2011). It is worth noting that in 2007, high-school students showed a prevalence of insufficient sleep of 68.9 % (Eaton et al. 2010). Insufficient sleep can be considered a common and long-standing condition (Hublin et al. 2001), and it is associated with considerable social, financial, and health-related costs (Durmer and Dinges 2005). Therefore, a better understanding of their deleterious effects not only in cognitive but also in emotional processing is of crucial relevance. The present study was aimed to assess the effects of low vigilance, due to sleep loss, on processing of emotional stimuli.

In general, our results showed impaired performance in a time window characterized by considerable decrements of subjective activation, affective tone, and body temperature (see also Casagrande et al. 2006; Durmer and Dinges 2005; Lorenzo et al. 1995; Martella et al. 2011; Pallesen et al. 2004). In fact, subjective energetic activation and affective tone decreased during nighttime, confirming previous well-known findings (Caldwell et al. 2004; Casagrande et al. 1997a, b, 1996; Curcio et al. 2001; Durmer and Dinges 2005; Marotta et al. 2014; Taillard et al. 2011). Additionally, impaired performance affected both facial and verbal emotional contents as it was indexed by slower RTs and higher percentage of errors in tasks that required recognizing the emotional valence of face expressions or words when they were performed under sleep deprivation conditions. Body temperature measures also followed the expected circadian rhythmicity (Czeisler et al. 1999; Wright et al. 2002). Accordingly, these results confirm the validity of the extended wakefulness protocol as it was scheduled for the present experiment.

A main objective of the present study was to determine whether the emotional content of different types of stimuli is differentially affected by sleep deprivation. For instance, it has been assumed that the emotional content of faces is not equally processed than the emotional content of words. Some studies have shown that people recognize positive faces faster than other expressions, including neutral faces (Kirita and Endo 1995; Leppänen and Hietanen 2003; Leppänen et al. 2004; Pérez-Dueñas et al. 2013). However, words with negative emotional valence seem to be recognized faster than words with either positive o neutral emotional valence (Estes and Verges 2008). Nevertheless, Pérez-Dueñas et al. (2009) did not find differences in recognizing positive and negative words, being both faster when compared with the recognition of neutral words. Pérez-Dueñas et al. (2009) used a cueing paradigm, and participants were grouped according to their scores in a trait anxiety scale. Thus, their results are not easily comparable with ours.

In the present study, we went further to ask whether sleep deprivation affected differentially the processing of emotional content depending also on the type of stimulus. Whereas sleep deprivation affected recognition of emotional content of words irrespective of their valence, recognition of emotional face expressions followed a different pattern of results. Neutral face expressions were clearly affected by sleep deprivation with both RT and accuracy measures. However, both positive and negative facial expressions were less affected by sleep deprivation compared with neutral facial expressions, although the way they were affected was different depending on how it was assessed. For instance, recognition of positive face expressions was affected by sleep deprivation when it was assessed through accuracy measures, but not when it was assessed by RTs. In contrast, recognition of negative face expressions was affected by sleep deprivation when it was assessed by RTs, but not when it was assessed by accuracy measures. Importantly, we conducted additional statistical analyses that took the sleep deprivation effect (SDE) as the dependent variable to assess how sleep deprivation affected performance. The results showed again that the different word valences were highly and equally affected by sleep deprivation. However, now only neutral face expressions were highly affected by sleep deprivation, whereas both positive and negative face expressions were less and equally affected. Although not statistically significant, the size of the SDE with positive face expressions was by half that of the SDE with negative face expressions (16 vs. 34; see Fig. 4).

The happy face advantage is a well-known phenomenon. Positive facial expressions are the fastest to be recognized (Kirita and Endo 1995; Leppänen and Hietanen 2003; Leppänen et al. 2004; Pérez-Dueñas et al. 2013), and are remembered better than other facial expressions (Shimamura et al. 2006). The attentional blink effect is smaller for both upright and inverted positive face icons than other face icons (neutral and angry faces) of corresponding orientations (Miyazawa and Iwasaki 2010). The slopes of the search functions for locating the negative face were shallower than the slopes of the search functions for locating the positive face (Eastwood et al. 2001). All these results suggest that the recognition of faces showing a positive expression is in some way facilitated. Emotional face expressions in general are therefore more resistant to the detrimental effects of sleep deprivation than neutral faces, but recognition of positive facial expressions is even more resistant.

Taken together, these results support the hypothesis that sleep deprivation effects are not exclusively associated with enhanced emotional brain reactivity toward negative stimuli (Yoo et al. 2007; Franzen et al. 2009), but also affects reactivity to positive experiences (Gujar et al. 2011). The fact that modulation of emotional processing by sleep deprivation was only observed with faces agrees with the high biological value of this kind of stimuli and therefore with higher automaticity in the sensory encoding of their emotional content compared with that of words (Fruhholz et al. 2011; Rellecke et al. 2011).

Before definitive conclusions can be derived from the differential patterns of sleep loss effects observed with faces and words, we should consider an alternative account. For instance, differences between faces and words might stem from the concrete schedule in which both tasks were carried out at night. The WR task was always performed at 6.00 am, whereas the FR task was always performed at 4.00 am. Given that both arousal (indexed by EA scores) and mood (indexed by AT scores) were reduced at 6.00 am compared with 4.00 am, the WR task was performed with lower levels of arousal and affective tone than the FR task. Nevertheless, the differential patterns of results were replicated when the differences in EA and AT between 4.00 and 6.00 am were taken into account. Although the time in which the two tasks were performed might have affected partially how sleep deprivation affected performance, our results suggest that it is the nature of the stimuli that determines to what extension sleep deprivation affects emotional processing. Future research with emotional tasks performed under equivalent arousal and mood levels should be conducted to confirm the present findings.

Conclusions

Sleep deprivation is associated with social, financial, and health-related costs and it increases the risk of human error (Durmer and Dinges 2005). Accidents related to sleep deprivation have been estimated to have an annual economic impact of $43 to $56 billion (Leger 1994). These data highlight the relevance of assessing how sleep deprivation affects both cognition and emotion. In the present study, we have shown that the detrimental effects of sleep deprivation on emotional processing very much depend on the nature of stimuli. Sleep loss affects considerably how words are recognized irrespective of their emotional valence. However, facial expressions seem to be a special class of visual emotional stimuli able to resist the impact of low arousal effects due to sleep deprivation, mainly when the face shows a positive expression. This is consistent with the view that faces' sensorial encoding is more automatic in comparison with sensorial encoding of words.

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