Elevated Ventral Striatal Reactivity to Reward Following Sleep Deprivation

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Introduction

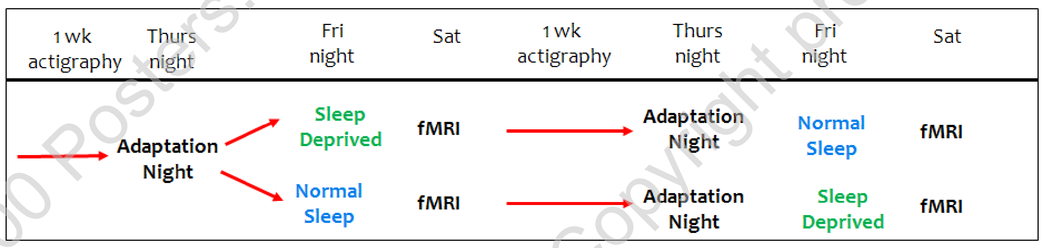
- Short sleep is linked to a range of negative physical and psychological consequences, including obesity, hypertension, anxiety/depression and suicidality (Grandner et al., 2010).
- Sleep loss also appears to increase unhealthy pursuit of rewards. Sleep deprived individuals make riskier decisions on gambling tasks (McKenna et al., 2007), and show increased preference for fatty, high carbohydrate foods (Nedeltcheva et al., 2009). Moreover, sleep deprivation increases cocaine self-administration in rats (Puhl et al, 2009), and sleep disturbance predicts subsequent relapse in alcoholics (Brower et al., 1998).
- Recent neuroimaging studies indicate that acute sleep deprivation may alter reward functioning by increasing sensitivity to reward-related stimuli in key reward neural circuitry including the ventral striatum (VS) (Venkatraman et al., 2007; 2011), putamen, and amygdala (Gujar et al., 2011).
- This study examined the impact of one night of sleep deprivation upon activity in reward neural circuitry in healthy late adolescents/young adults. We also examined whether variation in sleep during the five nights prior to testing had measurable associations with reward responding when participants were assessed following normal sleep and sleep deprived conditions.

Methods

Participant Characteristics

27 healthy young adults (age 18-25 years)
Mean age: 23.1 years
M/F: 11/16
Race: 20 Caucasian, 4 African American, 1 Asian American, 2 not specified

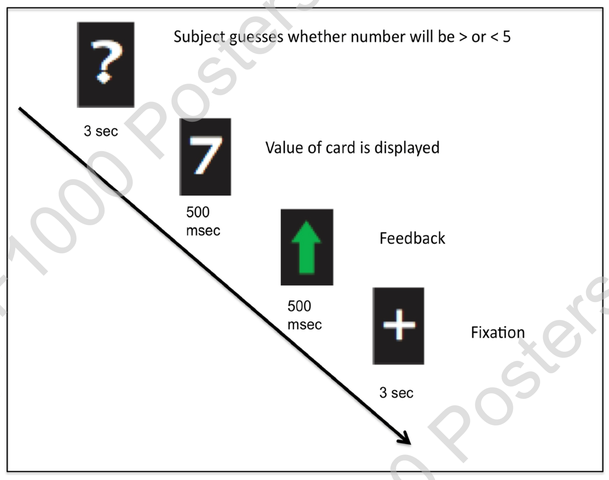
Procedure



Using a within-subjects crossover design, participants completed two experimental conditions (sleep deprivation; normal sleep) separated by at least 1 week. In the normal sleep condition, participants slept in the lab according to their habitual sleep schedule. In the sleep deprivation condition, participants denied sleep for one night. In the morning following each condition, participants completed functional magnetic resonance imaging (fMRI). During the 5 nights prior to each experimental condition, participants' sleep was assessed using wrist-worn actigraphy.

fMRI Paradigm

The Monetary Reward Task (Forbes et al., 2007) is a card guessing paradigm that requires participants to guess, via button press, whether the value of a card presented on screen will be less than or greater than 5. Participants win $1 for correct trials, or lose $.50 for incorrect trials. Outcome probabilities are fixed. Trials are organized into blocks of win (i.e., reward) and loss, as well as control blocks, in which participants respond to shapes but do not win or lose money.

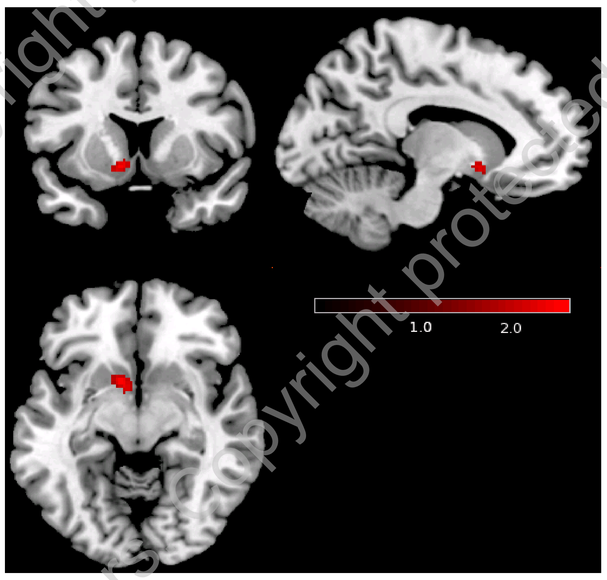


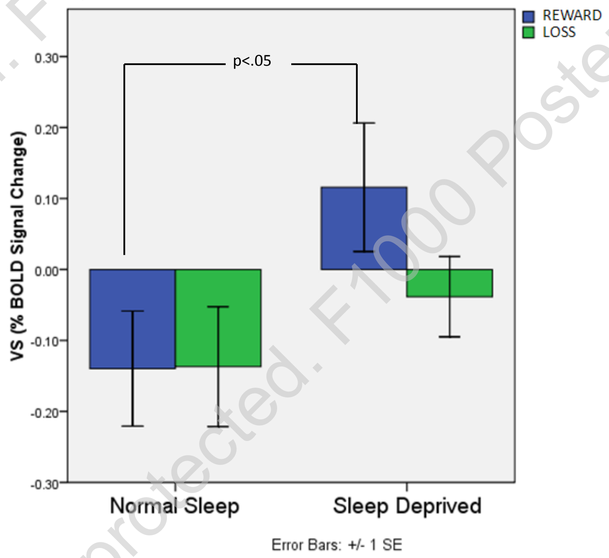
Imaging Analyses

- Images were pre-processed and analyzed using SPM8. We used a two-level random-effects analysis. At the first level, individual wholebrain statistical maps were constructed to evaluate the difference between the two feedback conditions (win and loss) and the control condition. These contrasts were then brought forward to second-level, paired sample t-test analyses.
- We used a region of interest (ROI) approach focused on the VS and medial prefrontal cortex (mPFC). The VS ROI consisted of bilateral 8mm radius spheres centered at Talairach coordinate 9, 9, -8 and -9, 9, -8. The 25mm radius mPFC sphere was centered at coordinate 0, 10, -10, encompassing anterior cingulate cortex (ACC) and medial segments of Brodmann's Areas 9 and 10.
- We extracted mean activity values for each participant for the VS and mPFC clusters derived from paired t-tests. These values were then correlated with mean total sleep time (TST) from the 5 nights before each condition.

Results

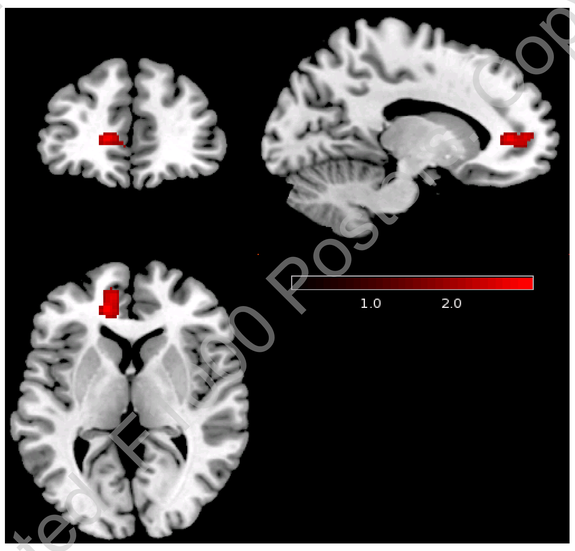
VS ROI: Reward during Sleep Deprivation>Normal sleep

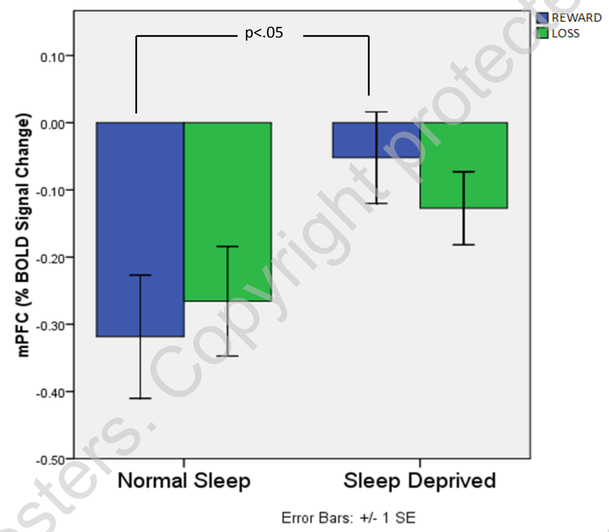




Left VS; $t(26) = 2.51$ $p=.006$; k= 68

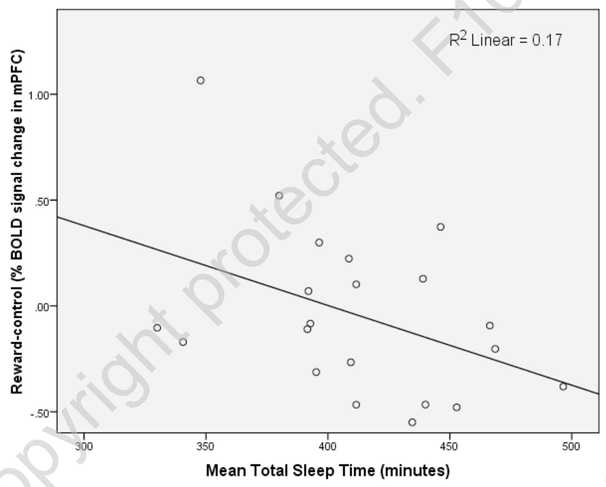
mPFC ROI: Reward during Sleep Deprivation>Normal sleep





Left ACC, BA 32; $t(26) = 2.93$, $p=.002$; k= 185

Association between ACC activity and TST prior to SD condition



- A marginally significant negative association (r=-.413, p=.06) was found between reward activity in the left ACC and mean TST in the 5 nights prior to the sleep deprivation testing . No significant associations were found between TST and VS activity to reward. Also, no associations were found between TST and reward-related BOLD activity during the Normal Sleep condition.

Conclusion

- Following acute sleep deprivation, healthy young adults exhibit abnormally increased activity in the VS and ACC during the winning of monetary reward. Aberrant functioning in reward neural circuitry, resulting in over-valuation of positively-reinforcing stimuli, could lead to impaired decision making and abnormally increased pursuit of reward.
- Decreased sleep prior to the full night of sleep deprivation appeared to increase the effect of sleep deprivation on reward-related activity in the ACC. This suggests that naturally incurred sleep debt, and not just acute doses of total sleep deprivation, has measurable effects on reward neural circuitry.
- Findings provide one possible neural framework for considering how chronic sleep loss might lead to chronic alterations in reward neural circuitry, contributing to the development of psychiatric conditions in which sleep and reward disturbance co-occur (e.g. bipolar disorder, substance use disorders).
- Future studies should examine the effect of sleep loss on reward neural circuitry in clinical conditions characterized by unhealthy reward pursuit, including compulsive gambling, binge eating, substance abuse, and bipolar disorder.

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