Stress and Sleep Interact to Enhance Memory Consolidation of Negative Events

Jessica D. Payne, Ph.D.
Sleep, Stress and Memory (SAM) Laboratory
Department of Psychology
University of Notre Dame
Stress and Memory

Stress often impairs (neutral) memory consolidation

Cortisol (corticosteroid) receptors are prevalent in the hippocampus

Distribution of glucocorticoid receptors in the mouse (A) and rat (B) hippocampus

Patel & Bulloch, 2003
Stress and Emotional Memory

Stress often enhances emotional memory consolidation
Stress and Emotional Memory

Stress often enhances emotional memory consolidation


Buchanan & Lovallo, (2001)
Stress and Emotional Memory

Stress often enhances emotional memory consolidation

Davidson & McEwen, 2012; Ghosh, Laxmi & Chattarji, 2013; McGaugh, 2004
Sleep and Emotional Memory

Sleep also enhances emotional memory consolidation

[Brain diagram showing regions with increased and decreased activity]
Sleep and Emotional Memory

Sleep also enhances emotional memory consolidation
Stimuli

Encoding

Retrieval

5 sec

24 Ss: 12hr wake/sleep delay

20 Ss: 30min morning/evening delay
Trade-off after a 30min Delay

Neutral Scenes

![Bar chart showing items recognized (%)](image)

- **30 min**
- **12 hr wake**
- **12 hr sleep**

**Legend:**
- object
- background

Emotional Scenes

![Bar chart showing the number of items recognized over time. The chart compares object and background items during 30 minutes and 12 hours wake.](chart)

Emotional Scenes

![Bar chart showing percentage of items recognized from emotional scenes under different conditions: 30 min wake, 12 hr wake, and 12 hr sleep.](chart)

- **Items Recognized (%):**
  - 30 min wake: 60%
  - 12 hr wake: 70%
  - 12 hr sleep: 90%

**Legend:**
- **object**
- **background**

*Payne, Stickgold, Swanberg & Kensinger, Psychological Science, 2008*
Changes in Memory Over 12 Hr of Wake or Sleep

Neural Correlates?

View pictures outside scanner, at 9AM (Wake) or 9PM (Sleep); retrieve memories while being scanned, either after day spent awake or night of sleep

Payne & Kensinger (2011) Journal of Cognitive Neuroscience
Conjunction Analysis: Regions Active Following Wake and Sleep

- Sleep
- Wake
- Both

Hippocampus
Retrieval of Emotional Objects Following Wake
Retrieval of Emotional Objects Following Sleep

- Amygdala
- Ventromedial PFC
- Sleep
- Wake
- Both
Sleep enhanced connectivity in emotional memory retrieval network during retrieval of emotional objects

Payne & Kensinger (2011) Journal of Cognitive Neuroscience
Sleep Stage Correlates?
Overnight Study

Payne et al., 2012
Overnight Emotional Memory Consolidation

- **REM Sleep (min)**
  - Correlation: $r = 0.57$, $p = 0.005$

- **REM Sleep (%)**
  - Correlation: $r = 0.58$, $p = 0.004$
Nap Study

12:00pm
Arrive in lab
Wire for PSG recording

Wake Group 1
Encode
Controlled Lab Activities
Test
Wake Group 2
Encode
Controlled Lab Activities
Test

1:00pm
Encode

5:30pm
Debrief and leave lab

87 min (avg)

Test

6:30pm
Controlled Lab Activities

time
Negative Emotional Scenes

Payne et al., 2015, Emotion
Nap

$r = .52, p = .01$

Payne et al., 2015, Emotion
Nap in middle-age adults

$r=0.34, p=0.01$

$r = 0.52, p = 0.01$

Alger & Payne, 2017

Payne et al., 2015
$r = .52, p = .01$

$NREM$ Delta Power (C4)

$NREM$ Delta Power (C3)

Emotional Objects Recognized

$r$ value
Sleep-Stress Interactions?

• Does stress/arousal around the time of encoding set the stage for selective emotional memory consolidation during subsequent sleep?
Stress and the Emotional Memory Tradeoff Effect

Like sleep, stress enhances emotional aspects of long-term memory relative to neutral aspects.

Payne et al., Under Review
Hypotheses:

- Higher cortisol levels at encoding would facilitate memory for emotional more than neutral stimuli
- This enhancing effect of cortisol on consolidation would be more pronounced if participants sleep (rather than stay awake) after encoding
Method

Encoding: 124 scenes

Each scene is 3 seconds long.

Negative or neutral object on neutral background.
Retrieval

- Following a sleep vs. wake delay, subjects retrieved memories in the scanner.
Cortisol level predicts selective memory for negative objects, but only in the sleep group

\[ R = .43, \ p = .031 \]

\[ R = -.10, \ p = .70 \]

Bennion, Mickley-Steinmetz, Kensinger & Payne, *Cerebral Cortex* (2015)
• **Sleep participants** with higher cortisol at encoding showed retrieval-related activity in emotional processing regions when they retrieved emotional objects:

Red: $p < .001$, 9 voxels; Pink: $p < .005$, 9 voxels

Bennion, Mickley-Steinmetz, Kensinger & Payne, *Cerebral Cortex* (2015)
Similar regions to those previously shown to be active during retrieval after Sleep but not Wake

Higher cortisol associated with stronger relation between looking time at encoding and activity in amygdala and mPFC during retrieval. This relation only true for those who slept.

Payne & Kensinger, 2011, JOCN

Retrieval activity correlated with pre-encoding cortisol level

Bennion et al., 2015, Cerebral Cortex

Payne & Kensinger, 2011, JOCN
Conclusions

- Cortisol during encoding leads to a stronger memory trace for negative objects, but only if sleep occurs during the consolidation interval (i.e., if consolidation is optimized)
- This is consistent with prior literature showing an enhancing effect of cortisol/stress during learning on emotional memory, while building on it in an important way:
  - Attributes the enhancing effects of cortisol on long-term emotional memory to consolidation during sleep
  - Supports the idea that elevated cortisol, and other arousal-related neuromodulators (NE) may help ‘tag’ encoded information as important to remember, enabling sleep-based consolidation to solidify that information
SCR response predicts selective memory for negative objects, but only in the sleep group

\[ r = .48, p = .04 \]

Cunningham et al., 2014
HRD score predicts selective memory for negative objects, but only in the sleep group.

Cunningham et al., 2014
Working Model

Arousing Event

NE/CORT

Tags set

Encoding

SLEEP

PRPs

Amy/HC/vmPFC potentiation

Theta, spindles, sharp wave-ripple events?

Consolidation

Retrieval

Time
Too Much of a Good Thing?

• Negative emotional remembering is adaptive, but only up to a point

• Ideally, one will remember the event, but strip away the affective reactivity associated with a traumatic event

• HPA axis dysregulation in PTSD and clinical depression (which are often co-morbid)

• Negative emotional memory bias in PTSD and clinical depression

• REM sleep dysregulation (REM measures often increased) in PTSD and clinical depression

• What is the best model connecting these features and what are the implications for treatment?
Lucid dreaming for memory modification?

Figure 1  Brain stimulation in the gamma frequency range during REM sleep enhances lucid dreaming. Voss et al. report that gamma stimulation during REM sleep enhances the ability to gain conscious awareness in dreams. Through achieving such lucidity, the sleeper in this image gains control over her dream and is able to fly.
Acknowledgements

- **Kelly Bennion**
- Chuck Crowell
- Elizabeth Kensinger
- Dan Schacter
- Nathan Spreng
- Robert Stickgold
- Matt Tucker
- Erin Wamsley
- Mike Villano
- Michelle Wirth

The SAMLab

- **Sara Alger**
- Sara Kim
- Tony Martinez
- **Tony Cunningham**
- Stephen Mattingly
- **Enma Pardilla-Delgado**
- Alexis Chambers
- NSF (BCS-0963581)
Acknowledgements