Nature Reviews Neuroscience | Published online 27 Jan 2017; doi:10.1038/nrn.2017.12

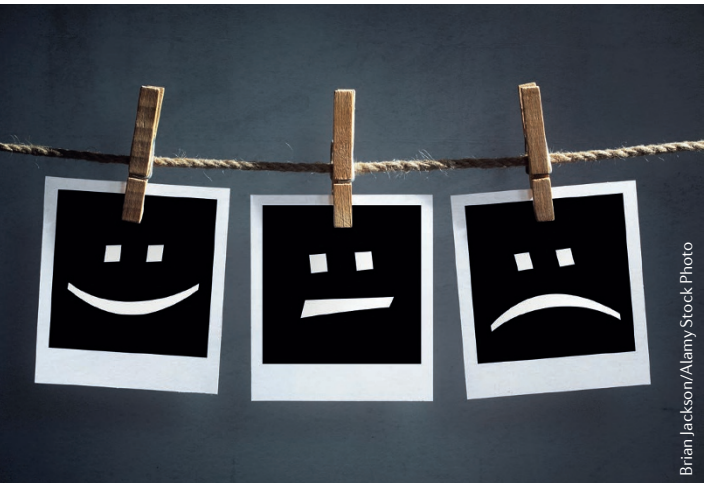
LEARNING AND MEMORY

I remember it well…

> neutral stimuli are more strongly remembered when experienced during an increased state of emotional arousal

People tend to remember emotional events more strongly and more clearly than those with no emotional associations, so-called neutral experiences. However, whether emotional experiences can affect the memory of subsequent neutral events is not known. In this study, Tambini *et al*. show that prolonged (as opposed to brief) exposure to emotional stimuli can induce alterations in brain state that last for many minutes after cessation of the stimuli and can strengthen the memory of neutral events that occur while these brain states persist.

Many previous studies showing that emotional arousal increases memory consolidation have suggested that this might occur because emotional arousal alters neurotransmission in the amygdala and, in turn, memory-related mechanisms in the hippocampus. Indeed, increased functional connectivity between the amygdala, hippocampus and medial temporal lobe cortex has been shown to be associated with improved memory. The authors reasoned that, if extended exposure to an emotional stimulus produced increases in functional connectivity between these areas that persisted beyond the cessation of the emotional stimulus, memory formation and consolidation for neutral and unconnected events encountered subsequently could be enhanced.



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The 44 participants in this study were exposed to 2 blocks of stimuli each lasting around 20 minutes, with a 9 minute break between them. The authors ordered the blocks in three combinations: emotional followed by neutral (E–N encoding order), neutral followed by emotional (N–E encoding order), and neutral followed by neutral (control). Throughout stimulus exposure, participants were scanned using blood-oxygen-level-dependent (BOLD) functional MRI. Six hours after the end of the last stimulus block, participants were given a memory test. The authors reasoned that, if extended exposure to emotional stimuli induced protracted changes in brain states, memory of neutral events should be enhanced only in the group that experienced the emotional stimuli first (E–N encoding order). Emotional arousal was determined by measuring skin conductance, a proxy indicator of sympathetic nervous system activation.

Participants' skin conductance increased during exposure to emotional (but not neutral) stimuli, and, in the E–N encoding order group, this increase persisted into the second block of neutral stimuli. In the memory test, participants in E–N and N–E groups demonstrated more accurate recollection of emotional stimuli compared with recollection of neutral stimuli, but participants in the E–N group showed higher accuracy in recollection of neutral stimuli. These findings indicate that neutral stimuli are more strongly remembered when experienced during an increased state of emotional arousal.

Given that the timescale over which these enhancements of recollection-based memory occur extends to many minutes, the authors asked whether changes in brain state that accompanied arousal could be tracked by alterations in low-frequency fluctuations in the BOLD signal (rather than by more transient, stimulus-evoked changes in the BOLD signal). Indeed, the global patterns of BOLD signal observed during the encoding of emotional stimuli were similar to those during presentation of neutral stimuli that followed exposure to emotional stimuli (E–N compared with N–E). The enhancement of emotional versus neutral memories is thought to involve the increased interaction between the amygdala and the anterior hippocampus (which are anatomically connected); here, increases in low-frequency connectivity between the amygdala and the anterior hippocampus associated with viewing the emotional stimuli were enhanced during neutral stimuli encoding in the E–N encoding order over that measured during neutral encoding in the N–E encoding order.

Together, these findings suggest that prolonged exposure to emotional stimuli results in increased functional connectivity between the amygdala and the hippocampus and strengthen the encoding of subsequent neutral stimuli.

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ORIGINAL ARTICLE Tambini, A. *et al.* Emotional brain states carry over and enhance future memory formation. *Nat. Neurosci.* http://dx.doi.org/10.1038/nn.4468 (2016)