Chapter 10
Evolutionary, Historical and Mechanistic Perspectives on How Stress Affects Memory and Hippocampal Synaptic Plasticity

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Abstract We have reviewed research on stress effects on brain and memory processing from evolutionary, historic, and mechanistic perspectives. Our view is that the stress response has been refined through the process of natural selection to provide a rapid activation of attention and memory-related neural systems in response to a threat to survival. Specifically, stress enhances synaptic plasticity in the hippocampus (in conjunction with amygdala activation) to generate a rapid, but time-restricted, enhancement of memory. The activation period, lasting only seconds to minutes, is followed by a period in which the hippocampus is relatively resistant to developing excitatory plasticity. One consequence of this rapid, but brief, activation of the hippocampus in response to intense stress is that life-threatening experiences can produce abnormal memories which represent only small fragments of the original experience. These fragmented memories of trauma are highly resistant to extinction, and underlie the intrusive memories commonly reported in people suffering from posttraumatic stress disorder (PTSD). This evolutionary-based perspective may provide insight into the neurobiological basis of traumatic memories and aid in the development of more effective treatments for individuals diagnosed with PTSD.

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Abbreviations

AMPA	α-amino-3-hydroxy-5-methyl-4-isoxazolepropionic acid
CaMKII	Ca^{2+}/calmodulin-dependent protein kinases II
CRH	Corticotropin-releasing hormone
GR	Glucocorticoid receptor
LTP	Long-term potentiation
MR	Mineralocorticoid receptor
NE	Norepinephrine
NMDA	*N*-methyl D-aspartate
PB	Primed burst
pMAPK2	Phosphorylated mitogen-activated protein kinase 2
PTSD	Posttraumatic stress disorder
VTA	Ventral tegmental area

10.1 Introduction: Evolutionary Perspective on Stress-Memory Dynamics

From an evolutionary perspective, the behavioral and physiological responses to stress have all developed to accomplish one goal: to maximize the likelihood an individual will survive a life-threatening experience. In particular, the stress response appears highly efficient at enhancing survival in response to an attack which has a high likelihood of producing structural damage. This stress adaptation is illustrated, for example, by the rapid stress-induced increase in blood glucose which mobilizes energy reserves to maximize an effective escape or attack. Moreover, stress promotes activation of the immune system and blood coagulation factors, processes that prepare an individual for wounds which may be inflicted during an attack (Sapolsky 1994). From a neuroethological perspective, a critical component of the stress response is activation of brain attention systems to maximize the processing of sensory components, which enable an individual to respond effectively to a threat. It is therefore of heuristic value to consider all components of the stress response to have been refined by the forces of natural selection to maximize survival in response to current and future life-threatening experiences.

How the brain forms memories of a stressful experience, however, is a challenge to understand from an evolutionary perspective. One may hypothesize that when a life-threatening experience occurs stress should provoke brain memory systems to generate highly accurate and durable memories, which can be of value if the individual survives the assault and then is faced with a similar threat in the future. This hypothesis is supported by the observation that intense stress can produce such powerful memories of the experience that they achieve a pathological status, as in the intrusive memories commonly reported in traumatized people diagnosed with posttraumatic stress disorder (PTSD) (Bryant et al. 2011; Ehlers et al. 2004). This perspective on emotional memory suggests that the cognitive component of PTSD

symptoms reflects an evolutionarily adaptive process, albeit, a process that has the capacity to go horribly awry.

A milder version of emotion-induced modulation of memory is described in the extensive literature on "flashbulb memories," which describes the phenomenon of enhanced memory processing for events and circumstances coincident with periods of high arousal (Brown and Kulik 1977). At a later time, the reappearance of cues which had been present at the time of the arousing experience is interpreted by the brain as a potential reemergence of the same threat to the individual's life. The memory of the original experience is activated, thereby enabling the individual to respond more effectively to the same situation, for example, by avoiding a place which was associated with predators. Although the precision with which flashbulb memories represent an accurate representation of the original experience has been debated (Laney and Loftus 2005; Loftus 2005; Schmidt 2004; Tekcan et al. 2003), their general accuracy and durability, which can span decades, is remarkable (Berntsen and Thomsen 2005; Tekcan and Peynircioglu 2002; Van der Kolk 1997). Therefore, findings from human and animal research indicate that an experience that evokes strong arousal, particularly in life threatening conditions, generates enduring memories of the event.

Although the findings of the veracity and durability of emotional memories are consistent with the evolutionary value of enhanced memory processing in response to life-threatening experiences, a thorough review of the literature reveals a more complex story on the modulation of memory by stress. Over a century of research has provided a vast and seemingly conflicting literature providing evidence that stress not only enhances memory, it can also impair memory in rodents and people (Buchanan et al. 2006; Diamond et al. 2007; Elzinga et al. 2005; Kim et al. 2006; Kirschbaum et al. 1996; Payne et al. 2002, 2006; Roozendaal et al. 2009; Schwabe et al. 2010, 2012; Wolf 2009). This more comprehensive assessment of the complexity of the stress-memory literature is not consistent with the hypothesis that stress nonspecifically enhances memory storage.

Despite the complexity of the stress-memory literature, we remain guided by the principal that stress-memory interactions, in step with all other physiological processes, have been refined by natural selection to maximize survival in response to a life-threatening stimulus. In this chapter, we discuss a refined hypothesis which takes into account the adaptive value of the complexity of stress-memory interactions. Specifically, we consider the initiation of an attack to be the moment when an individual's survival is at greatest jeopardy, which thereby makes this relatively brief period of time crucial for optimizing brain attention and memory processing. Our hypothesis is that memory storage is optimal for events occurring during the brief period of time (seconds to minutes) around the onset of an experience that generates a sudden increase in attention and arousal. In contrast to this brief memory enhancing period at stress onset, events that occur well before or long after the initiation of the stress experience would not be remembered as well. This time-dependent dynamic shift in memory processing provides an ethologically relevant approach toward understanding the complexity of memory processing in response to stress.

Our hypothesizing on the time-dependency of memory processing during intense stress provides a foundation for enhancing our understanding of stress-related psychiatric disorders. For example, a core feature of PTSD includes pathologically intense, intrusive, and extinction-resistant memories of the traumatic experience (Debiec et al. 2011; Milad et al. 2009; Rougemont-Bucking et al. 2011). To improve our understanding of PTSD and to provide a background on memory, stress and psychopathology, in the next section we review research which has examined how stress affects the hippocampus, a structure which is central to emotional and non-emotional memory processing (Eichenbaum 2004). We conclude this chapter with a discussion of physiological mechanisms which appear to underlie the dynamic time-dependent shifts in brain-memory processing that determine whether events occurring during heightened emotion will be remembered or forgotten.

10.2 Historical Perspective on How Acute Stress Affects Hippocampal Functioning

Pioneering studies on stress and the brain were performed by Bruce McEwen and his colleagues who determined that the hippocampus has the greatest density of corticosteroid receptors in the brain (McEwen et al. 1969, 1968). These findings indicated that the hippocampus, in addition to its crucial role in memory formation, was also highly sensitive to stress. In related work, McEwen's group suggested that prolonged stress, via glucocorticoid receptor (GR) activation, impairs hippocampal function (Micco Jr. et al. 1979). The view of stress interfering with hippocampal functioning was incorporated into theorizing on hippocampal functioning by Jacobs and Nadel (Jacobs and Nadel 1985) who suggested that the stress-induced disruption of hippocampal functioning contributed to the expression of psychiatric disorders. Hence, early studies implicated acute stress as having a detrimental influence on hippocampal functioning.

In the decades since McEwen's pioneering research, studies on stress and synaptic plasticity have further supported the view that stress impairs hippocampal functioning. The first such evidence from electrophysiological studies on synaptic plasticity was provided by Thompson and coworkers, who demonstrated in 1987 that acute stress blocked the induction of hippocampal long-term potentiation (LTP) in vitro (Foy et al. 1987), a physiological model of memory formation (Miller and Mayford 1999; Muller et al. 2002). At that time our group was investigating how acute stress or corticosterone affected a low threshold form of LTP, referred to as primed burst (PB) potentiation, in vivo (Diamond et al. 1988; Rose and Dunwiddie 1986). We reported that adrenalectomized, and therefore corticosterone-depleted, rats exhibited a greater magnitude of PB potentiation than adrenal intact rats (Diamond et al. 1989), which suggested that corticosterone exerted an inhibitory influence on hippocampal plasticity. We then extended this work with the finding of an overall inverted U-shaped function between corticosterone levels and PB

potentiation (Diamond et al. 1992), thereby providing strong support for the hypothesis that stress levels of corticosterone exerted a profound inhibitory effect on hippocampal functioning.

In behavioral work, we reported that the induction of PB potentiation was blocked in rats that were exposed to an unfamiliar, and therefore stress-provoking, environment (Diamond et al. 1990, 1994). We also showed that when rats were explicitly acclimated to the environment, as indicated by a significant reduction in their levels of serum corticosterone, the blockade of PB potentiation was no longer present (Diamond et al. 1994). Importantly, when these same rats were then exposed to a second, stress provoking (corticosterone-elevating) environment, once again, PB potentiation was suppressed. These findings demonstrated that the capacity for the hippocampus to generate plasticity, and presumably its memory storage functioning, was continuously influenced by an animal's emotional state; under stress conditions hippocampal functioning was impaired and when the stress abated hippocampal functioning resumed its normal capacity to process and store memories.

Subsequent work conducted over the past two decades by our laboratory, as well as work from numerous other groups have replicated the finding of a stress- or corticosterone-induced suppression of hippocampal synaptic plasticity. For example, we demonstrated that stress blocked the induction of PB potentiation in vivo (Diamond et al. 1999a; Vouimba et al. 2006) and in vitro (Mesches et al. 1999). Complementary findings from other groups have shown that acute stress or corticosterone administration can block hippocampal LTP (Cazakoff and Howland 2010; Diamond et al. 2007; Huang et al. 2005; Joels and Krugers 2007; Schmidt et al. 2013; Schwabe et al. 2012; Segal et al. 2010); (see Segal et al. (2010) for discussion of differences in stress and corticosterone effects on hippocampal plasticity in the dorsal versus ventral hippocampus).

In addition to work on synaptic plasticity, studies on learning and memory in rodents and people have provided strong evidence that stress impairs cognitive aspects of hippocampal functioning. For almost two decades our group has shown that stress, involving exposure of rats to either an unfamiliar environment or to a live cat, impairs hippocampus-dependent spatial memory (Campbell et al. 2008; Conboy et al. 2009; Diamond et al. 1996, 1999b, 2006; Sandi et al. 2005; Woodson et al. 2003). Our findings are consistent with work from other laboratories indicating that acute stress or corticosterone administration can impair hippocampus-specific memory processing in rats and people (Joels et al. 2008, 2011; Schwabe et al. 2012; Yehuda et al. 2010).

This brief overview of studies on stress and synaptic plasticity summarizes the prevailing view that strong stress inhibits hippocampal functioning (Acheson et al. 2012; Brewin 2001; Diamond et al. 2005; Jacobs and Nadel 1985; Joseph 1999; Kim and Yoon 1998; Kim and Diamond 2002; Kim et al. 2006; Layton and Krikorian 2002; LeDoux 1996; Metcalfe and Jacobs 1998; Nadel and Jacobs 1998; Van der Kolk 1996). It can therefore be stated with certainty that stress can impair the capacity for the hippocampus to generate excitatory synaptic plasticity, and that stress interferes with the involvement of the hippocampus in the storage of information.

10.3 Temporal Dynamics of Stress-Plasticity Interactions: Resolving the Paradox of How the Hippocampus is Involved in the Formation of Stressful Memories

The attentive reader may be forgiven for being perplexed by the historical perspective we just provided as to how stress affects hippocampal synaptic plasticity and memory. In the first section of this chapter we emphasized the evolutionary value of enhancing memory under stressful conditions, which was reinforced by our brief review of the durability and accuracy of emotional (flashbulb) memories. We also referred to the vast research literature confirming that the integrity of the hippocampus has long been demonstrated to be essential for the formation of declarative (fact-based, episodic) memories. The paradox is that stress produces intense and durable episodic memories, as exemplified by flashbulb and intrusive memory phenomena, and yet, the literature provides strong evidence that stress impairs the functioning of the hippocampus, a structure at the center of brain memory circuitry. To resolve this paradox, we will revisit the hypothesis we presented in the introductory section regarding dynamic changes in memory processing in response to stress. We speculated that it is the onset of an intense emotional experience, as in the immediate response to an attack by a predator, which is the critical time to optimize memory storage. Hence, focusing on memory, and specifically hippocampal processing, for events occurring around the onset of a stressor may resolve the inconsistencies in the literature as to how stress affects the brain and memory.

Empirical research relevant to our hypothesis has been provided in the work by Ehlers et al. (2002) in their analysis of intrusive memories reported by traumatized people. These investigators examined the relation between intrusive memories for trauma and the timing of events occurring during traumatic experience. People who had experienced severe trauma identified features of their intrusive memories (a core symptom of PTSD). Most subjects reported visual intrusive memories of stimuli or events that occurred immediately before or at the onset of the traumatic event. For example, one patient who had experienced a head-on car crash at night saw headlights coming towards her as a prominent component of her intrusive memories of the experience. Ehlers and coworkers suggested that because these stimuli occurred in close temporal proximity to the traumatic event, they became "warning signals," or stimuli that, if encountered in the future, would indicate something dangerous is about to happen. These authors noted that events occurring more distant from the initiation or peak period of trauma were less likely to be incorporated into intrusive memories.

At extreme levels of emotionality the memory storage process underlying the "warning signal" phenomenon can become pathological, as in the intrusive memories which interfere with the traumatized person's sleep quality, and more globally, with the person's quality of life. Nevertheless, from a neuroethological perspective, the intrusive memories suffered by a traumatized person represent an adaptive process since the repeated rehearsals of the traumatic experience (via intrusive memory reactivation) primes the individual to be more sensitive to the

warning signal in the future. Even impaired sleep quality, which is a central feature of the PTSD diagnosis, is adaptive from an evolutionary perspective; suppressing sleep is a strategy with which the brain can ensure that the individual is always on-guard to respond more effectively to warning signals which were associated with a threat.

Although the "warning signal" hypothesis of Ehlers and coworkers was not presented in a neurobiological framework, its primary emphasis, of maximal memory storage for events occurring at the onset of a stress experience, has been addressed in experimental and theoretical work in behavioral neuroscience research. Specifically, there is a small, and perhaps overlooked, subset of electrophysiological research that has demonstrated that manipulations, which produce strong emotionality in rats, can *enhance* hippocampal LTP. This finding was first described by Seidenbecher et al. (1995), who showed that water-deprived rats given access to water around the time of tetanizing stimulation exhibited an *increase* in the duration of hippocampal LTP. Other studies have replicated and extended this finding to show that a variety of arousing experiences, such as water immersion, exposure to novel places and objects, and spatial learning occurring around the time of the delivery of tetanizing stimulation, all increased the duration of LTP (Ahmed et al. 2006; Almaguer-Melian et al. 2005; Davis et al. 2004; Frey 2001; Li et al. 2003; e.g., Seidenbecher et al. 1997; Straube et al. 2003; Uzakov et al. 2005); but see (Tabassum and Frey 2013).

The rapid effects of stress on enhancing hippocampal plasticity appear to be mediated, in part, by amygdala–hippocampus interactions (Kim and Diamond 2002). Studies demonstrating the enhancing effect of amygdala activation effects on hippocampal LTP were originally provided by Akirav and Richter-Levin (Akirav and Richter-Levin 2006; Bergado et al. 2011; Richter-Levin and Akirav 2003; Richter-Levin 2004). These investigators showed that stimulation of the amygdala 30 s, but not 1 h, prior to perforant path stimulation of the hippocampus enhanced LTP in the DG. These findings of a time-dependent modulation of hippocampal plasticity by amygdala stimulation or stress are consistent with our work in which stress blocked the induction of PB potentiation in vivo and in vitro (discussed above); in our research tetanizing stimulation has always been delivered at least 1 h, and as many as 4 h, after the stress manipulation began. Work from other laboratories, as well, that have shown inhibitory effects of stress on LTP involve necessary amygdala activation (Kim et al. 2001, 2005), in conjunction with prolonged stress (at least 30 min) prior to the delivery of tetanizing stimulation (Alfarez et al. 2002; Foy et al. 1987; Garcia et al. 1997; Shors et al. 1997). Overall, these findings indicate that for a relatively brief period of time, stress via amygdala activation enhances the hippocampal synaptic plasticity, followed by a later developing phase when the induction of LTP is suppressed.

Therefore, the dominant theme of stress uniformly impairing hippocampal LTP has not incorporated conflicting findings, which have demonstrated that stress can enhance, as well as impair, the induction of hippocampal synaptic plasticity. The enhancement of LTP by stress appears to be confined to conditions in which the stress and tetanizing stimulation occur in close temporal proximity; in contrast, the

suppression of LTP occurs when there is a prolonged delay between the time of stress onset and the delivery of tetanizing stimulation.

This view of dynamic temporal shifts in processing by the hippocampus has been a topic of extensive theorizing in the past decade. For example, Joels et al. (2006) theorized regarding the role of corticosterone in the time-dependent effects of stress on memory and LTP. In related work, Richter-Levin and coworkers (Bergado et al. 2011; Richter-Levin and Akirav 2003; Richter-Levin 2004) proposed the "emotional tagging" hypothesis, which states that there is a selective activation of synapses in the hippocampus and amygdala in response to arousing experiences. In related theorizing, we proposed the temporal dynamics model (Diamond et al. 2007), which addressed the implications of strong emotionality briefly activating hippocampal mechanisms of synaptic plasticity, thereby increasing the duration of LTP, followed by a prolonged period of inhibition. We speculated that the relatively brief stress-induced enhancement of hippocampal functioning underlies the declarative component of flashbulb and traumatic memories in people, and contextual fear conditioning in rodents. In theory, following the brief period in which hippocampal plasticity is activated is a refractory period, in which there is an increase in the threshold for the induction of new plasticity and new learning. We provided support for our hypothesis with the finding that brief (2 min) stress coincident with the time of spatial learning strengthened spatial memory, but more prolonged stress impaired spatial memory, as well as contextual (hippocampal-dependent), but not cued (hippocampal-independent), fear memory (Diamond et al. 2007). Recently, Schwabe et al. (2012) elaborated on these issues with a comprehensive review of the temporal dynamics of stress–memory–brain interactions.

The mechanisms underlying the enhancement of hippocampal plasticity by stress act, in part, by modulating NMDA receptor-based synaptic plasticity. Rapid stress-induced increases in hippocampal glutamate levels (Bagley and Moghaddam 1997; Musazzi et al. 2011; Piroli et al. 2013) increase AMPA receptor-mediated postsynaptic depolarization, followed by the transient removal of the magnesium block on the NMDA channel. Continued glutamate-mediated activation of the AMPA and NMDA receptors enables calcium ions to enter the NMDA channel, thereby increasing postsynaptic calcium concentration, triggering a cascade of events (including CaMKII activation and autophosphorylation) involved in the strengthening of synaptic activity (Nicoll and Malenka 1999).

The extensive series of studies conducted by Joels and coworkers is relevant to the rapid stress-induced modulation of NMDA- and non-NMDA-dependent synaptic plasticity. These investigators have shown that brief application of corticosterone around the time of tetanizing stimulation enhanced LTP in CA1 in vitro via nongenomic activation of mineralocorticoid receptors (MRs) (Karst et al. 2005; Wiegert et al. 2006), which rapidly enhance mEPSP frequency and glutamatergic neurotransmission. In addition, activation of membrane MRs facilitates lateral diffusion of GluA1 and GluA2 subunits and enhances activity dependent insertion of AMPA receptors (Groc et al. 2008).

Complementary work by Ahmed et al. (2006) demonstrated that brief stress transforms protein synthesis-independent LTP into a long-lasting protein synthesis-dependent form of LTP, via activation of MRs. This group also showed that stress rapidly initiated dynamic changes in gene expression (Morsink et al. 2006), and levels of cellular signaling molecules in the hippocampus, including phosphorylated mitogen-activated protein kinase 2 (pMAPK2) and calcium/calmodulin-dependent protein kinase II (pCaMKII). Conversely, stress levels of corticosterone applied for a longer period of time (>20 min) increased the magnitude of inhibitory components of electrophysiological activity, such as the afterhyperpolarization (Joels and Kloet 1989, 1991; Karst et al. 1991) and reduced NMDA receptor-mediated plasticity (Krugers et al. 2005), thereby suppressing the induction of LTP (Alfarez et al. 2002; Kerr et al. 1994; Krugers et al. 2005; Pavlides et al. 1993, 1995a, 1995b, 1996; Rey et al. 1994; Zhou et al. 2000).

In addition to corticosterone, other neuromodulators contribute to the rapid, but brief, stress-induced enhancement of synaptic plasticity. For example, the dopaminergic innervation of the hippocampus from the ventral tegmental area (VTA) produces a rapid enhancement of hippocampal synaptic plasticity (Li et al. 2003; Lisman and Grace 2005). Moreover, brief exposure of rats to a novel environment (something considered to be a mild stressor) produced a dopamine-dependent enhancement in CA1 LTP (Li et al. 2003). In addition, projections from the locus coeruleus, in response to an arousing experience, produce a rapid release of norepinephrine (NE) into the hippocampus and amygdala, which interact with elevated levels of glucocorticoids, to enhance hippocampal excitability, plasticity, and overall function (Kitchigina et al. 1997; McGaugh et al. 1996; McIntyre et al. 2003; Roozendaal et al. 2006; Sara et al. 1994; Valentino and Van Bockstaele 2008). Specifically, the stress induced activation of the locus coeruleus has been shown to enhance excitability in the dentate gyrus of the hippocampus (Harley and Sara 1992; Kitchigina et al. 1997), which is dependent on adrenergic β-receptor activation (Hopkins and Johnston 1988; Sarvey et al. 1989). In addition to the NMDA-mediated calcium influx discussed previously, activation of β-receptors enhances calcium influx through voltage dependent L-type calcium channels via upregulation of cAMP (Gray and Johnston 1987). This NE-mediated calcium influx contributes to enhanced LTP, in part, through β-receptor dependent increases in cAMP levels and enhanced activity of PKA and CaMKII which have been shown to enhance phosphorylation of GluR1 subunits and facilitate synaptic insertion of AMPA receptors (Hu et al. 2007). Together with the MR-mediated insertion of AMPA receptors (discussed above), NE release in response to a stressful event further enhances excitability in the hippocampus.

Finally, corticotropin-releasing hormone (CRH) is a critical factor in neuroendocrine modulation of brain activity. CRH is released from hippocampal interneurons in response to stress (Chen et al. 2004) and has been shown to rapidly influence hippocampal electrophysiological activity (Aldenhoff et al. 1983). CRH has also been shown to enhance synaptic efficacy in the dentate gyrus of the hippocampus in (Wang et al. 1998). Though brief application of CRH has been shown to enhance

excitability and LTP in the hippocampus (Kratzer et al. 2013), prolonged application of CRH, perhaps mimicking delayed effects of stress, has been shown to impair hippocampal LTP (Rebaudo et al. 2001). Thus, CRH, as well as corticosterone, exhibit rapid and delayed effects on hippocampal synaptic activity, which reflect their participation in the dynamic time-dependent modulation of hippocampal functioning by stress.

Ultimately, rapid stress-induced elevations in glutamate levels in the hippocampus followed by increased influx of intracellular calcium are necessary for memory formation, but continued influx of postsynaptic calcium can lead to excitotoxicity (Foster and Kumar 2002). Therefore, following the rapid enhancement of plasticity, NMDA receptors desensitize to reduce calcium influx and prevent glutamate-induced neurotoxicity (Zorumski and Thio 1992). The desensitization of NMDA receptors would serve the dual purpose to protect the neurons from excitotoxicity, as well as to minimize the corruption of the memory from events occurring long after the onset of the stress initiation (Laney and Loftus 2005).

10.4 Summary

We have provided our perspective on how stress affects memory, in general, and specifically, how the hippocampus is affected by acute stress. We have critiqued the global hypothesis that a stress response involves a global enhancement of attention and memory processing. Instead, we have suggested that there is a relatively brief period of time around the initiation of a stress experience in which maximal memory processing occurs. Our discussion of dynamic shifts in the processing of synaptic plasticity, and therefore optimal memory processing, addresses the complexity and heterogeneity of the literature on how stress affects memory and synaptic plasticity. The apparent paradox that stress produces flashbulb and traumatic memories that can last a lifetime, and yet, stress blocks hippocampal synaptic plasticity, is resolved by taking into account the temporal dynamics of changes in hippocampal functioning following stress onset. That is, is a rapid stress-induced enhancement of hippocampal plasticity, followed soon after by a prolonged period of inhibition of plasticity. This time-based shift in hippocampal functioning creates an isolated (temporally fragmented) memory of events that were coincident with the onset of the stress. This perspective on the neural basis of emotional memories is relevant to the finding that traumatic intrusive memories reported by people with PTSD are described as representing only temporally disjointed fragments of the trauma, rather than as a continuous representation of the entire experience (Rubin et al. 2004).

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