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Post-learning arousal enhances veridical memory and reduces false memory in the Deese-Roediger-McDermott paradigm

Kristy A. Nielson [a,b,*], Anthony N. Correro II [a]

[a] Department of Psychology, Marquette University, United States
[b] Department of Neurology and the Center for Imaging Research, Medical College of Wisconsin, United States

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ABSTRACT

The Deese-Roediger-McDermott (DRM) paradigm examines false memory by introducing words associated with a non-presented 'critical lure' as memoranda, which typically causes the lures to be remembered as frequently as studied words. Our prior work has shown enhanced veridical memory and reduced misinformation effects when arousal is induced *after* learning (i.e., during memory consolidation). These effects have not been examined in the DRM task, or with signal detection analysis, which can elucidate the mechanisms underlying memory alterations. Thus, 130 subjects studied and then immediately recalled six DRM lists, one after another, and then watched a 3-min arousing (n = 61) or neutral (n = 69) video. Recognition tested 70 min later showed that arousal induced after learning led to better delayed discrimination of studied words from (a) critical lures, and (b) other non-presented 'weak associates.' Furthermore, arousal reduced liberal response bias (i.e., the tendency toward accepting dubious information) for studied words relative to all foils, including critical lures and 'weak associates.' Thus, arousal induced after learning effectively increased the distinction between signal and noise by enhancing access to verbatim information and reducing endorsement of dubious information. These findings provide important insights into the cognitive mechanisms by which arousal modulates early memory consolidation processes.

1. Introduction

Memories are not snapshots of events that individuals have experienced (Bartlett, 1932). In fact, some things are better remembered than others, while some recollections are distorted or inaccurate. The Deese-Roediger-McDermott (DRM; Deese, 1959; Roediger & McDermott, 1995) paradigm demonstrates this distinction, providing an experimental framework to elicit and assess the activation of false memory traces while also assessing veridical memory. In this task, lists of related words constructed around a specific, but non-presented theme word (i.e., "critical lure"), are studied. The critical lures are frequently misremembered on a later recognition test as having been previously studied (Deese, 1959; Roediger & McDermott, 1995).

The degree to which words on a list are associated with a critical lure, also known as their associative strength, is particularly important to how the dominant theories explain the DRM phenomenon. The activation-monitoring theory and the fuzzy-trace theory, each a "dual process" theory of false memory, make similar predictions regarding how the DRM paradigm is able to foment false memories. In activation-monitoring theory (Roediger, Watson, McDermott, & Gallo, 2001), it is proposed that studying the associates causes spreading activation that ultimately activates the lure within semantic networks. This leads to a source monitoring error during testing whereby individuals believe that the critical lure was studied when it is actually new. Activation-monitoring theory is supported by findings of increased false memory when there is greater associative strength within word lists, and findings that DRM lists produce more false memory than categorized lists, where gist is high, but associative strength is lower (see Gallo, 2010). With fuzzy-trace theory, it is proposed that information is encoded into two distinct memory traces: one verbatim and one gist (e.g., Brainerd, Reyna, & Kneer, 1995). Verbatim traces contain item-specific information representing the subjective experience of encoding, while gist traces represent common semantic attributes amongst the encoded words. The critical lures from DRM themes are strong gist traces that readily create false memories. Fuzzy trace theory is supported by false memory occurring for perceptually similar but unfamiliar or unknown pictures and objects that have no pre-existing semantic associations, and through the

* Corresponding author at: Department of Psychology, Marquette University, P.O. Box 1881, Milwaukee, WI 53201-1881, United States.
E-mail address: kristy.nielson@marquette.edu (K.A. Nielson).

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presence of unrelated items in recognition testing yielding enhanced false memory compared with lists only including semantic associates (see Gallo, 2010). Thus, both activation-monitoring theory and fuzzy-trace theory can explain false memories through the semantic relatedness of list items to critical lures.

The DRM task has also been used to study the effects of emotion and arousal on memory. Currently, there are discrepancies in the literature regarding the directionality of the effect and what actually causes it. An important distinction between emotion and arousal helps elucidate some of the current controversies. Emotion typically refers to an affective state experienced by a person in response to a particular object or situation (Clore & Huntsinger, 2007), which can be positive or negative (i.e., valence), while arousal is defined as a range of vigilance, alertness, sympathetic activation, or responsiveness to stimuli (Revelle & Loftus, 1992; Russell, 1980). Importantly, emotion and arousal are not orthogonal; both are components of an emotional experience (Revelle & Loftus, 1992), and it is difficult to identify stimuli that produce highly positive or negative valence ratings without also producing high arousal ratings (Lang, Greenwald, Bradley, & Hamm, 1993).

Studies that focused generally on the effect of valence have differed somewhat from studies that attempted to disentangle valence from arousal in the DRM. For example, Storbeck and Clore (2005) examined emotion irrespective of arousal by eliciting positive or negative mood using music during encoding. Negative mood led to a decrease in false memory, but positive mood and no mood induction resulted in a similar rate of false recall (although greater than the negative mood condition). The results were explained using an affect-as-information framework (Clore et al., 2001), suggesting that negative affect triggers item-specific processing (i.e., a focus on individual list items leading to verbatim memory traces), while positive affect elicits relational processing (i.e., prominently gist-based memories are formed). In contrast, studies using stimuli that span both valence and arousal dimensions have often pointed to the importance of arousal to DRM effects. One such study examined each dimension using mood induction for valence (i.e., elated, depressed, or neutral) and exercise for arousal. While mood induction failed to influence memory, low arousal led to an "overly general" style of autobiographical memory retrieval (McBride & Cappeliez, 2004). Van Damme (2013) attempted to expand upon such work in a series of three experiments. Her study used the DRM paradigm with one of six pre-learning, music-based mood conditions spanning the valence-arousal spectrum: control (no mood induction), neutral, negative/high arousal (angry), negative/low arousal (sad), positive/high arousal (happy), and positive/low arousal (serene). Each list was followed by an arithmetic distraction task. Retention of all lists en masse was assessed immediately after the final list/distraction procedure. The results showed a reduction of false memory in the higher arousal conditions, regardless of valence (see Anderson, Wais, & Gabrieli, 2006; English & Nielson, 2010; Nielson & Powless, 2007). Furthermore, signal detection analyses revealed that the arousal effect was due to enhanced discriminability of studied words versus critical lures and reduced liberal responding to critical lures.

Most studies to date have manipulated emotion or arousal before or during learning (e.g., Buchanan & Lovallo, 2001; Corson & Verrier, 2007; Kensinger & Corkin, 2004; Mather et al., 2006; Storbeck & Clore, 2005; Van Damme, 2013). In such studies, the effects of the manipulation may be on any aspect of the memory process, including attention, encoding, motivation, rehearsal, and consolidation; the effect on a specific aspect of the memory process cannot be isolated. Thus, differences in timing or context of the manipulation may contribute to some of the discrepancies in the literature. Memory consolidation, first proposed by Müller and Pilzecker (1900), is the foundational process of assuring memory storage for later retrieval. It consists of a complex series of neurobiological processes that occur over time after the original learning (see McGaugh, 1990, 2000, 2013, 2015; Nielson & Powless, 2007; Revelle & Loftus, 1992; Torras-Garcia, Portell-Cortes, Costa-Miserachs, & Morgado-Bernal, 1997). Thus, many animal studies and some human studies have isolated the memory consolidation phase by manipulating arousal *after* encoding (e.g., Anderson et al., 2006; English & Nielson, 2010; Nielson & Arentsen, 2012; Nielson & Jensen, 1994; Nielson & Lorber, 2009; Nielson & Powless, 2007; Nielson, Yee, & Erickson, 2005). These studies, as well as others (e.g., Wang, 2013), have consistently demonstrated that moderate arousal, regardless of direction of mood or valence, enhances delayed memory. The retention interval for these studies has ranged from roughly 30 min to one week after learning, with remarkably comparable effects. Indeed, Anderson et al. (2006) showed that such effects are demonstrable after a few minutes.

Arousal as a modulator of memory consolidation is practical from an evolutionary standpoint. That is, by enhancing retention of arousing information and events, arousal allows an organism to remember and distinguish between important and mundane experiences (McGaugh, 1990). Multiple endogenous substances that are released during moderately arousing situations have been linked with the modulation of memory consolidation. These typically result from the adrenergic response to arousal and include epinephrine, norepinephrine, and glucose (see Czech, Nielson, & Laubmeier, 2000; Gold & McCarty, 1981; Nielson, Czech, & Laubmeier, 1999; Nielson & Jensen, 1994; van Stegeren, Everaerd, Cahill, McGaugh, & Gooren, 1998). Through multi-faceted pathways, adrenergic substances influence amygdala activity, which in turn influences hippocampal neurons, followed by broader systems changes in cortical and other subcortical regions involved in memory (e.g., Clewett, Sakaki, Nielsen, Petzinger, & Mather, 2017; Mather, Clewett, Sakaki, & Harley, 2015; McGaugh, 2006; McGaugh & Roozendaal, 2002). The effects of each of these substances showing the typical inverted-U dose-response patterns such that moderate doses tend to enhance memory while small or large doses can impair it (McGaugh, 2000; Yerkes & Dodson, 1908). Indeed, higher levels of arousal, such as situations involving fear or threat, are more likely to be characterized as stressful and produce a corticosteroid response, which can impair memory retrieval processes and exacerbate false memory (Pardilla-Delgado, Alger, Cunningham, Kinealy, & Payne, 2016; Payne, Nadel, Allen, Thomas, & Jacobs, 2002; Smeets, Jelicic, & Merckelbach, 2006).

As the process of consolidation takes time, the retention interval may limit or allow for the phase and extent of consolidation to be examined. Earlier stage consolidation processes (often termed cellular consolidation), which are thought of as primarily hippocampal processes with secondary cortical contributions, are more likely tapped with retention tests occurring within hours of learning (see Genzel & Wixted, 2017). As more hours, days or weeks pass, which also allows for sleep to occur, systems consolidation, which taps more extensive and cortical contributions to memory consolidation, is more likely to have occurred (see Genzel & Wixted, 2017). The retention interval for human studies that manipulate arousal to influence memory consolidation has ranged from roughly minutes to one or two weeks after learning, thereby traversing these early and later stages. Yet, the studies with delays ranging from over 30 min to weeks have produced remarkably comparable retention profiles (e.g., Anderson et al., 2006; English & Nielson, 2010; Nielson & Arentsen, 2012; Nielson & Jensen, 1994; Nielson & Lorber, 2009; Nielson & Powless, 2007; Nielson et al., 2005). Thus, retention tests occurring within hours of learning may only reflect early or shorter term consolidation processes and it is uncertain, without longer delayed testing, whether those effects will last. The consistency in findings across such studies suggests that they may invoke sufficient initiation of