Available online at www.sciencedirect.com
SCIENCE DIRECT®
Neurobiology of Learning and Memory 84 (2005) 49–56
Neurobiology of Learning and Memory
www.elsevier.com/locate/ynlme

Memory enhancement by a semantically unrelated emotional arousal source induced after learning

Kristy A. Nielson [a,b,c,*], Douglas Yee [a], Kirk I. Erickson [a]

[a] Department of Psychology, Marquette University, Milwaukee, WI 53201-1881, USA
[b] Integrative Neuroscience Research Center, Marquette University, Milwaukee, WI 53201-1881, USA
[c] Foley Center for Aging and Development, Department of Psychiatry and Behavioral Medicine, Medical College of Wisconsin, USA

Received 18 January 2005; revised 3 April 2005; accepted 4 April 2005
Available online 10 May 2005

Abstract

It has been well established that moderate physiological or emotional arousal modulates memory. However, there is some controversy about whether the source of arousal must be semantically related to the information to be remembered. To test this idea, 35 healthy young adult participants learned a list of common nouns and afterward viewed a semantically unrelated, neutral or emotionally arousing videotape. The tape was shown after learning to prevent arousal effects on encoding or attention, instead influencing memory consolidation. Heart rate increase was significantly greater in the arousal group, and negative affect was significantly less reported in the non-arousal group after the video. The arousal group remembered significantly more words than the non-arousal group at both 30 min and 24 h delays, despite comparable group memory performance prior to the arousal manipulation. These results demonstrate that emotional arousal, even from an unrelated source, is capable of modulating memory consolidation. Potential reasons for contradictory findings in some previous studies, such as the timing of "delayed" memory tests, are discussed.

Keywords: Memory consolidation; Heart rate; Galvanic skin response; Electrodermal activity; Skin conductance; Long-term memory; Emotion; Memory modulation; Arousal

1. Introduction

It has long been known that some events or facts are remembered better than are others and that emotionally arousing events are recollected with greater frequency than similar but emotionally neutral events. From a number of perspectives enhanced memory for emotional events is adaptive, effectively making important stimuli stand apart from those that are less significant (McGaugh, 1990), and thus protecting and preparing an organism for similar occasions in the future. Many psychological studies have investigated factors that might explain the memory advantage for emotional events, such as enhanced attention and elaboration (e.g., Revelle & Loftus, 1992; Walker, 1958). Although these factors play a role in the memory advantage of emotionally charged information, they are likely insufficient to explain it (e.g., Bohannon, 1988; Conway et al., 1994; Guy & Cahill, 1999). Less often discussed are the neural and endogenous hormonal mechanisms that are preferentially engaged in response to arousing or emotive stimuli that can enhance memory (cf. Gold & McGaugh, 1975; McGaugh, 1990, 2000).

Memory consolidation, the means of storing a memory, is the outcome of a complex set of neurobiological processes occurring over a period of time (cf. Deutsch & Deutsch, 1966; McGaugh, 2000; Müller & Pilzecker, 1900; Torras-Garcia, Portell-Cortes, Costa-Miserachs, & Morgado-Bernal, 1997). As such, events occurring during, or even shortly after learning can alter, or modulate,

* Corresponding author. Fax: +1 414 288 1796.
E-mail address: kristy.nielson@marquette.edu (K.A. Nielson).

1074-7427/$ - see front matter © 2005 Elsevier Inc. All rights reserved.
doi:10.1016/j.nlm.2005.04.001

the consolidation of memory. Although emotional events naturally involve arousal onset during the event itself, it typically persists also for some time afterward. Therefore, like other arousal sources, emotion can have physiological effects on memory consolidation, rather than just on encoding and attention. Indeed, although arousal can facilitate detection and encoding for long-term retention, it can also hinder retrieval for as much as 30 min (Revelle & Loftus, 1992; Walker, 1958).

A variety of substances, including glucose and the adrenal hormones epinephrine, norepinephrine, and cortisol are released into the bloodstream during times of arousal, stress and emotion (Gold & McCarty, 1981) and have been closely linked to memory enhancement (e.g., Czech, Nielson, & Laubmeier, 2000; McGaugh, 2000; Nielson, Czech, & Laubmeier, 1999; Nielson & Jensen, 1994; van Stegeren, Everaerd, Cahill, McGaugh, & Gooren, 1998). Many animal studies have consistently shown that these substances alter memory and that they generally follow the classic inverted-U dose–response effect (Yerkes & Dodson, 1908) on memory performance (McGaugh, 1990, 2000). These effects are also time-dependent, such that doses administered during or shortly after learning are effective, but those administered 30 min or 2 h after learning are ineffective (Gold & van Buskirk, 1975; but see also Powless et al., 2003).

Most of the research on the processes of memory modulation has been done in animal models. The animal research demonstrating a locus of the effect of memory modulators on the consolidation process is important for evaluating the results of human studies, which have instead primarily manipulated arousal during encoding. In seeming conflict to what would be expected based on the findings in the animal literature, a number of authors of human studies have concluded that arousal only affects memory if it is *semantically related* to the material being remembered, purportedly because high attentional selectivity induced by arousal is assumed to interfere with memory (i.e., Easterbrook, 1959). For example, Christianson and Mjörndal (1985) found that epinephrine injections, an unrelated arousal source, produced physiological and subjective arousal but did not enhance memory performance for faces over saline injections. Christianson, Nilsson, Mjörndal, Perris, and Tjelldén (1984) also found that saline injected participants shown traumatic pictures remembered significantly less than epinephrine injected participants shown neutral materials (i.e., unrelated arousal source). Buchanan and Lovallo (2001) found that pre-learning injections of cortisol selectively enhanced delayed memory for arousing pictures but not neutral pictures. Varner and Ellis (1998) did two experiments manipulating mood and arousal state either before or after learning. They found mood- and theme-congruence effects, but physiological arousal via exercise did not affect word retrieval. Finally, Libkuman, Nichols-Whitehead, Griffith, and Thomas (1999) examined source of arousal on memory for details in a series of experiments finding that emotional arousal enhanced memory but physiological arousal by exercise had no effect. They concluded "…in order for arousal to have any impact on memory, it must be relevant to the to-be-remembered event; merely arousing someone will not suffice (p. 180)."

At best the relationship amongst emotion or arousal and memory is as yet incompletely understood. Although the human studies described have significantly contributed to our understanding of the effects of emotion on memory, each also had significant limitations precluding strong conclusions about the role of arousal per se in memory. In some studies, the degree of arousal achieved in the experiment was potentially too high to enhance memory (e.g., Christianson et al., 1984), and in some studies, memory for different materials was compared across groups (e.g., Christianson et al., 1984; Libkuman et al., 1999), or sources of arousal were combined from external and stimulus sources, which clouds the issue of the effect of arousal source on memory. Importantly, in most of these studies, arousal was manipulated during the encoding phase of the tasks employed, which confounded the effects of arousal on attention and encoding with its effects on consolidation (Buchanan & Lovallo, 2001; Christianson & Mjörndal, 1985; Christianson et al., 1984; Libkuman et al., 1999). Finally, previous animal and human research makes clear that memory consolidation takes time (e.g., McGaugh, 2000; Revelle & Loftus, 1992; Walker, 1958), but each of these previous studies used very short-term retention tests (10–15 min delay), potentially missing the effects of the arousal manipulation (Buchanan & Lovallo, 2001; Christianson & Mjörndal, 1985; Christianson et al., 1984; Libkuman et al., 1999; Varner & Ellis, 1998). Indeed, a recent study showed that an emotional version of a story produced better 1-week delayed retrieval of the story than did a neutral version, but there was no difference in retrieval when only a short 1 h delay was used (Quevedo et al., 2003).

Studies specifically examining the effects of arousal on the memory *consolidation* process in humans are limited. Nicotine (Colrain, Mangan, Pellett, & Bates, 1992), glucose (Manning, Parsons, & Gold, 1992), and muscle tension (Nielson & Jensen, 1994; Nielson, Radtke, & Jensen, 1996) have been shown to enhance delayed retrieval of non-arousing memory materials when given after learning. For example, Nielson and Jensen (1994) showed that induction of muscle tension shortly after exposure to target words embedded in paragraphs increased heart rate and enhanced delayed recall and recognition of the words, except in participants who were taking β-blockers to control hypertension. Importantly, immediate retrieval was not affected by arousal. Similarly, a list-learning study showed that hypermnesia, improvement in memory over time, was inhibited by showing a violent