



# The impact of different emotional states on the memory for what, where and when features of specific events

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## HIGHLIGHTS

- We investigated the impact of emotional states on what, where and when memory.
- An anxious emotional state impaired the memory for the location of events in virtual reality.
- High levels of negative arousal were associated with poor memory for the temporal and spatial context of events.
- High levels of happiness were associated with better memory for the spatial context of events.

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## ABSTRACT

Emotions can modulate the encoding and recollection of personal events. In the present study, we investigated the effects of different emotional states (pleasant, neutral or anxious) on episodic memory formation in a virtual reality (VR) setting. Emotional states were induced by pleasant, neutral or anxiety-inducing movie clips prior to the presentation of specific events in a VR scenario. Episodic memory performance of healthy participants in whom an anxious emotional state had been induced was inferior to those of the neutral and pleasant conditions. In the anxious condition, participants were particularly impaired regarding their memory for the location of events. A correlational analysis indicated that high levels of negative arousal were associated with poor memory for the temporal and spatial context of events. In contrast, high levels of happiness were associated with better memory for the spatial context of events. Our data provide evidence that emotional arousal can modulate memory for what happened, where and when.

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## 1. Introduction

The permanent storage of personal life events is dependent upon the amount of emotional arousal induced by the experience [1]. Emotionally arousing experiences are retrieved more vividly than neutral events [2–6]. The emotional arousal that accompanies a significant event is integrated into the episodic memory system and is likely to be the basis of the feelings of vividness, intimacy, and involvement that are associated with the recollection of a past personal experience [2,4,7,8].

In addition to the retrieval of the details or content, episodic memory involves the remembrance of the contextual details associated with a specific personal event. Thus, the episodic memory system integrates information about the specific location in which an event occurred (WHERE information) and the specific time period associated with this event (WHEN information) [2–4,7]. To date, much less is known about the effect of emotional arousal on the contextual aspects of an episodic memory. In particular, it is not well understood whether and to what extent emotions affect the storage and retrieval of content, spatial and temporal information differentially. So far, studies have mainly addressed this question by examining the impact of emotional valence on the memory for items (e.g., words, pictures) in contrast to the memory for source information (e.g., background color or spatial location used during the presentation of an item). A general finding from these

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studies is that the recollection of emotionally arousing/valenced items (words, pictures, etc.) is better relative to neutral items (e.g. Ref. [9]). Although some studies have shown that source memory (defined as the remembrance of the background color of a word) was better when emotional words relative to neutral words were presented [9–12], opposing effects of emotions on source memory have also been reported [13,14]. Recently, Schmidt et al. [15] examined whether an item's valence (positive, negative) or arousal (high, low) has an impact on the retention of the contextual details of the corresponding learning experience. Their results indicated that high-arousal items were more frequently remembered in conjunction with their spatial and temporal learning context than low-arousal items. In contrast, item valence had no influence on the memory for spatial and temporal details.

The studies mentioned above have tested the effects of item valence on source or context memory, using study items that induced emotional arousal themselves [9–15]. It has to be acknowledged that items that induce higher levels of arousal are better remembered than items that trigger low levels of arousal. Therefore, the present study was aimed at investigating the effects of emotional states on the memory for neutral events in their spatial and temporal context. Our approach is intended to understand how mood and anxiety disorders that are associated with chronic changes in arousal levels affect event or episodic memory formation.

In the past two decades, the investigation of episodic-like memory in animals has generated novel behavioral paradigms [16–19,20]; reviewed in Ref. [21]. These behavioral paradigms based on the memory for what, where and when (following a reverse translational approach) have also influenced the way episodic memory formation and retrieval is measured in human studies [3,22–26]. For example, we have adapted the episodic-like memory task in rodents for use in humans and developed a paradigm that measures the spatio-temporal memory for emotional and neutral material [22,23]. Others used movie clips of naturalistic material [23,27] and/or VR techniques [28,29] to assess the memory for what, where and when features of unique experiences.

Recently, we demonstrated that this paradigm is sensitive to episodic memory decline in the course of aging [23]. Interestingly, we found that age-dependent episodic memory deficits were associated with lower trait anxiety scores. This finding suggests that hypo-emotionality might interfere with episodic memory formation because personal experiences with emotional content do not easily surmount the arousal threshold for the induction of episodic memory formation [2–4,30]. It is elusive, however, whether an emotional state affects the memory for what, where and when features of personal experiences differentially.

In the present study, we used a novel virtual reality based approach to assess the influence of different emotional states on quantitative as well as qualitative aspects of episodic memory formation [2–4] in healthy participants. As a readout for the vividness of the episodic memories formed, we also measured the memory for event details [9,31,32]. We hypothesized that the induction of emotional states should modulate the episodic memory formation of neutral events.

## 2. Methods and materials

### 2.1. Participants

Healthy subjects were recruited via board advertisements at the Ruhr-University of Bochum, Germany, and online social networks. Exclusion criteria were the existence of a psychiatric record or a severe and/or chronic health issue that would prohibit testing,

a severe visual impairment, substance abuse and a prior history of neurological diseases. All participants had a corrected to normal vision. Participants were randomly assigned to one of three experimental conditions. The experimental procedure in each condition was identical except for the different movie clips presented that either induced an anxious, neutral or pleasant emotional state (see emotional state induction for further details). Data from nine participants were discarded due to following reasons: technical errors during the procedure, participants reporting motion sickness during the test in VR or the participants returning incomplete questionnaires during the testing procedure. All experimental procedures were approved by the local ethical committee of Ruhr-University of Bochum, Germany, and carried out in accordance with the declaration of Helsinki. Participants either received 10 Euro or a research participation course credit.

### 2.2. Questionnaires

To determine possible influences of trait depression, anxiety and stress tension on memory performance, each participant received selected items from the Depression Anxiety Stress Scales (DASS; [33]). Furthermore, the Immersive Tendencies Questionnaire (ITQ; [34]) as well as the Igroup Presence Questionnaire (IPQ; [35]) were used to determine the degree of immersion upon episodic memory performance in VR.

### 2.3. Emotional state induction

The induction of different emotional states in healthy participants was performed according to a standardized procedure recently used by Vriends et al. [36]. Depending on the experimental condition, each participant watched a specific 1.5-min movie sequence (either anxious, happy or neutral) prior to each of the three entrances into the VR scenarios. The film sequences were chosen from ca. 4.5-min movie clips, which were split into three sequences of each ca. 1.5-min duration on each trial. The film material used, i.e., movie scenes from “Halloween” [37], “All the President's Men” [38], and “The Jungle Book” [39] for the anxious, neutral, and happy emotional state induction, respectively, was shown to be reliably effective in eliciting different emotional states in healthy individuals [36,40]. Prior to and after each movie clip presentation, participants filled in 4 paper-and-pencil visual analogue scales with the anchors ‘absolutely not anxious’ vs. ‘very anxious’, ‘absolutely not happy’ vs. ‘very happy’, ‘absolutely not negatively aroused’ vs. ‘very negatively aroused’ and ‘absolutely not positively aroused’ vs. ‘very positively aroused’ (see Ref. [36]).

### 2.4. The what-where-when memory test in VR

Each participant was subjected to a specific VR scenario on three different time-points. On each time-point, participants were asked to “walk-through” an apartment in which a particular event took place. The events were neutral and hence unlikely to be perceived as aversive (see Fig. 1 for an illustration of the events encountered). Each event involved a particular person who was neither visually nor thematically related to the specific event. Both the events and persons were presented in different rooms on each of the three VR walk-throughs. During the second and third walk-through, specific standard items located in the rooms were either rearranged or remained the same (for example a distinct lamp located in the room was switched on or off). Each participant had an overview of the whole room whenever he/she entered a specific room. After the third VR walk-through and a predetermined delay (see Section 2.5), the episodic memory test was conducted.

During the unexpected memory test participants were subjected to two different categories of questions. In the first category

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