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

Armin Zlomuzica[a,*], Friederike Preusser[a], Christina Totzeck[a], Ekrem Dere[b,c], Jürgen Margraf[a]

[a] Mental Health Research and Treatment Center, Ruhr-University Bochum, Bochum, Germany
[b] UFR des Sciences de la Vie (927), Université Pierre et Marie Curie, Paris, France
[c] Max Planck Institute of Experimental Medicine, Göttingen, Germany

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.

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

* Corresponding author at: Mental Health Research and Treatment Center, Ruhr-University Bochum, Bochumer Fenster, Massenbergstraße 9-13, 44787 Bochum, Germany.
E-mail address: armin.zlomuzica@rub.de (A. Zlomuzica).

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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

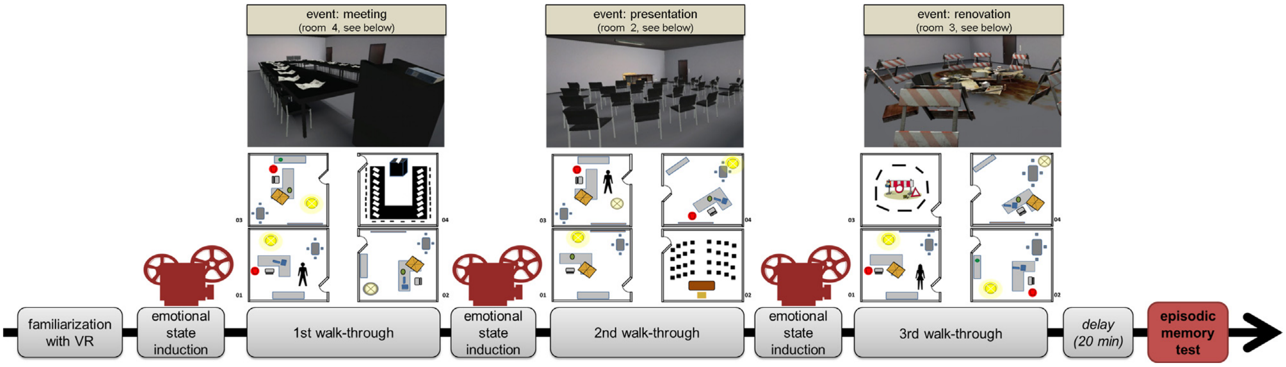

Fig. 1. Schematic of the experimental design. Subjects were first familiarized with the virtual reality setup during a 5 min training phase. Prior to each of the three walk-throughs, short movie sequences were presented to elicit either an anxious, happy or neutral emotional state. During each of the three walk-throughs, participants were exposed to the same sequence of VR scenario in that they were to explore 4 rooms (see lower panel). One of the rooms contained a specific person (male or female; see lower panel) while yet another room contained a specific event. The event and person encountered varied across the three walk-throughs with respect to the room they were located in (see lower panel) and their content. The content of the events during each walk-through are depicted in the top panel (please note that these are real images from the VR environment); they involved either a meeting (1st walk-through), a presentation (2nd walk-through) or a renovation (3rd walk-through). In addition, each room contained specific items (e.g., a desk depicted as a grey rectangular, see lower panel), which were either rearranged or remained the same across the walk-throughs. For example, a lamp was either switched on (yellow dot) or off (gray circle with an X). After participants had completed the 3rd walk-through, a delay of 20 min was imposed, at the end of which the unexpected memory test was conducted. During the test, participants were asked to retrieve scenario-related details (event and person-related information) as well as scenario-unrelated details (peripheral information) from the walk-throughs. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

(Scenario-related memory), participants received either pictures of events or a layout of the VR apartment and were asked to remember: i.) when a particular event had taken place (WHAT-WHEN event-related) and/or person had been encountered (WHAT-WHEN person related) as well as to indicate ii.) at which location an event (WHAT-WHERE event-related) or a person (WHAT-WHERE person-related) had been presented. Additionally, participants received questions concerning specific details directly connected to the persons and/or the scenarios themselves (Scenario-related scene details). For instance, they were asked to remember the color of clothes a particular person wore or items embedded in the specific scenarios.

In the second category of questions (Scenario-unrelated memory), participants also received a combination of WWW questions and questions concerning details that surrounded the specific events and/or persons but were not part of the scenario itself. For instance, participants were asked whether a characteristic item was present or not in one of the adjacent room(s) during the presentation of a specific scenario or whether a distinctive lamp was switched on or off in the adjacent room(s) during a specific event.

Group differences in terms of memory performance were examined, using 3 performance scores for each participant: (A) Scenario-related memory score; score ranging from 0 to 19. (B) Scenario-unrelated memory; with the lowest and highest scores being 0 and 31, respectively. (C) Total episodic memory score based on the sum of scenario-unrelated memory and scenario-related memory, with scores ranging from 0 to 50.

2.5. General procedure

Upon arrival, each participant was informed about the putative content of the study and the general procedure. Thereafter, informed consent was signed and each participant was asked to complete a set of standardized questionnaires including demographic information and questions about the current and past health status. Participants were told that they would participate in an experiment investigating the effect of emotions on perception. No explicit instruction was given about the exact purpose of the study. Most importantly, since our aim was to create a situation in which experienced events are likely to be encoded spontaneously by the episodic memory system, participants were neither explicitly instructed to retain any information presented during the course of the experiment nor were they told that a memory test would be performed afterwards. In this regard, the learning situation was also designed in a way that should minimize the utilization of memory systems different from episodic memory and the use

Table 1
Demographic, psychometric and control measures of the study groups.

Variable	Study groups		
	neutral (n = 23) M (SD)	positive (n = 27) M (SD)	anxious (n = 25) M (SD)
Age (years)	22.22 (3.26)	23.85 (4.07)	22.04 (3.54)
Gender (% female)	56.5	51.9	60
DASS depression	2.22 (2.81)	1.52 (1.42)	2.24 (3.07)
DASS anxiety	1.52 (2.33)	1.37 (1.80)	1.96 (1.79)
DASS stress	6.17 (4.72)	5.89 (3.14)	6.16 (2.85)
DASS total	9.91 (8.57)	8.78 (5.35)	10.36 (5.81)
ITQ focus	28.09 (3.83)	26.22 (3.85)	27.2 (5.44)
ITQ involvement	25.96 (4.71)	23.11 (5.69)	22.48 (6.59)
ITQ games	3.74 (2.96)	3.37 (3.08)	3.76 (3.05)
IPQ general presence	2.96 (1.49)	2.85 (1.88)	3.24 (1.45)
IPQ spatial presence	14.74 (6.72)	14.33 (7.21)	15.68 (4.47)
IPQ involvement	12.13 (4.81)	11.89 (6.25)	13.04 (5.33)
IPQ experienced realism	8.52 (3.81)	7.59 (3.80)	7.36 (3.40)

Note. DASS; depression anxiety stress scales, ITQ; immersive tendencies questionnaire, IPQ; Igroup presence questionnaire.

of specific learning strategies including the active rehearsal of the information (see Ref. [3]). Before the actual experiment started, participants were familiarized with the VR task in a 5 min training phase. Here, events different to those later used in the experimental task were presented and the participant had the opportunity to actively move and explore the VR environment. Upon completion of the training phase, each participant was informed that he/she will watch a short movie clip on the computer monitor prior to each of three entrances into specifically designed VR apartments (for details on emotional state induction see Section 2.3). Participants were briefly informed about the content of the movie clip and were thereafter asked to put on headphones. Subsequently, the participant was asked to rate his/her emotional state on the visual analogue scales, and after the movie clip had been presented, participants again completed the visual analogue scales and the first of the three VR walk-throughs was initiated. Participants were instructed to carefully explore the entire VR apartment. They were further instructed to explore freely each of the 4 rooms in the VR apartment for a maximum of 120 s. After 120 s had elapsed, the experimenter reminded them to move to the next room. This procedure was conducted for two additional times in the same manner, albeit different sequences from the respective movie and different VR scenarios were presented. Immediately after the third VR walk-through, a delay of 20 min was imposed, during which participants completed another set of questionnaires. Thereafter, the episodic memory test was conducted (for details see Section 2.4). At the end of the experimental procedure, participants' experience with playing video-games was recorded. Also, participants were asked whether the movie material was familiar to them and whether they had expected that certain items or persons related to the movie material would be present in the VR apartment. A brief outline of the experimental design is depicted in Fig. 1.

2.6. Statistical procedures

Statistical analyses were performed with the SPSS Statistics 20.0 (IBM) software package. Emotional induction checks were analyzed by means of mixed ANOVAS. In addition, difference scores (Diff Score = score post induction minus score pre induction) were calculated to examine whether emotional activation was changing over the 3 walk-throughs. Furthermore, the intensity of emotional activation was defined as the mean score of all 3 post-ratings (calculated separately for each scale). Non-parametric statistics using the Kruskal–Wallis and Mann–Whitney *U*-tests for pair-wise multiple comparisons were computed to compare performance in the episodic memory test between the groups. Correlations were obtained using two-sided Pearson correlations. All P-values given are two-tailed and are considered to be significant when $p < 0.05$.

3. Results

There were no significant differences between the experimental groups regarding age [$F(2,72) = 1.934$, $p = 0.152$], or gender distribution $X^2(2) = 0.353$, $p = 0.838$ (cf. Table 1). The groups did not differ with respect to the total DASS score [$F(2,72) = 0.394$, $p = 0.676$)], nor on its subscales [all $F(2,72) \leq 0.694$, $p \geq 0.503$]. Thus, pretest scores on negative emotional states of depression, anxiety, and stress were similar across the groups. All groups performed similar on the subscales of the ITQ [all $F(2,72) \leq 2.480$, $p \geq 0.091$] as well as on the Igroup Presence Questionnaire [$F(2,72) \leq 0.666$, $p \geq 0.517$], suggesting that the degree of immersion in VR was comparable across groups (cf. Table 1).

Table 2
Performance scores and test statistics of the groups in the episodic memory test.

	Emotional Induction Conditions[b] (Mean Ranks)			Kruskal–Wallis	
	Neutral	Positive	Anxious	$x^2(2)$	*p*
Scenario-related Memory	45.09[a]	39.31	30.06	5.963	0.051
WHAT-WHEN	41.74	40.15	32.24	3.509	0.173
Event-related	39.52	40.33	34.08	2.407	0.300
Person-related	41.13	39.19	33.84	2.275	0.321
WHAT-WHERE	41.91	39.33	32.96	2.318	0.314
Event-related	43.63[b]	40.76[c]	29.84	7.219	0.027
Person-related	39.48	38.67	35.92	0.399	0.819
SCENE details	44.76	38.06	31.72	4.567	0.102
Scenario-unrelated memory	37.96	39.80	36.10	0.376	0.828
Total episodic memory score	41.85	39.52	32.82	2.268	0.322

Note: [a–c] denote significant pair-wise comparisons with the anxious group, with [a] $p = 0.014$, [b] $p = 0.014$, and [c] $p = 0.045$; Mann–Whitney *U* test.

3.1. Emotional state induction

To determine whether the emotional state induction was effective, we performed a series of 3 × 2 mixed measures ANOVA with group (neutral vs. anxious vs. pleasant) as the between-subject factor and time (before and after film induction) as the within-subject factor, separately for each of the 3 walk-throughs and each of the 4 emotional scales. Our analyses demonstrated that the emotional state induction affected the groups differently as evidenced by significant *time x emotional state* interactions for each combination of walk-through and emotional scale [all $F(2,72) \geq 4.977$, $p \leq 0.009$], thus indicating successful induction of emotional states. Systematic increases and/or decreases in intensity of emotion ("anxiety" vs. "happiness") and arousal ("positively aroused" vs. "negatively aroused") from pre-induction to post-induction are presented in Fig. 2.

In addition, a series of ANOVAs on the intensity of emotional activation (mean score) revealed significant between-group differences on each scale [all $F(2,72) \geq 4.960$, $p \leq 0.012$]. Post-hoc comparisons showed that the anxious group exhibited significantly higher scores after the emotional state induction on the "anxiety" scale as compared to the pleasant and neutral group (all $p < 0.001$), as well as higher scores on the "negative arousal" scale as compared to the pleasant group ($p < 0.001$). Similarly, the pleasant group indicated a happier mood and more positive arousal than the anxious group (all $p \leq 0.009$) after the film presentation.

In order to determine whether the change in emotional activation (Diff Score) varied over repeated walk-throughs in VR, yet another series of mixed ANOVA's with walk-through (first, second and third) as within subjects factor and group as between-subjects factors were conducted for each scale separately. Except for positive arousal ['main effect' walk-through, $F(2,144) = 4.645$, $p = 0.011$], the Diff Scores were similar on each walk-through [all $F(2,144) \leq 0.459$, $p \geq 0.633$].

In general, there was no influence of film familiarity on the intensity of emotional activation (mean score, all $p \geq 0.184$). However, only within the neutral emotional state group the familiarity of the film had a slight impact on the positive arousal scale ($t(21) = 2.106$, $p = 0.047$).

3.2. WWW memory

Performance scores of the groups in the WWW memory test are summarized in Table 2. Generally, there were no between-group differences in the total episodic memory score ($p > 0.05$; Kruskal Wallis Test). Likewise, groups performed similar with

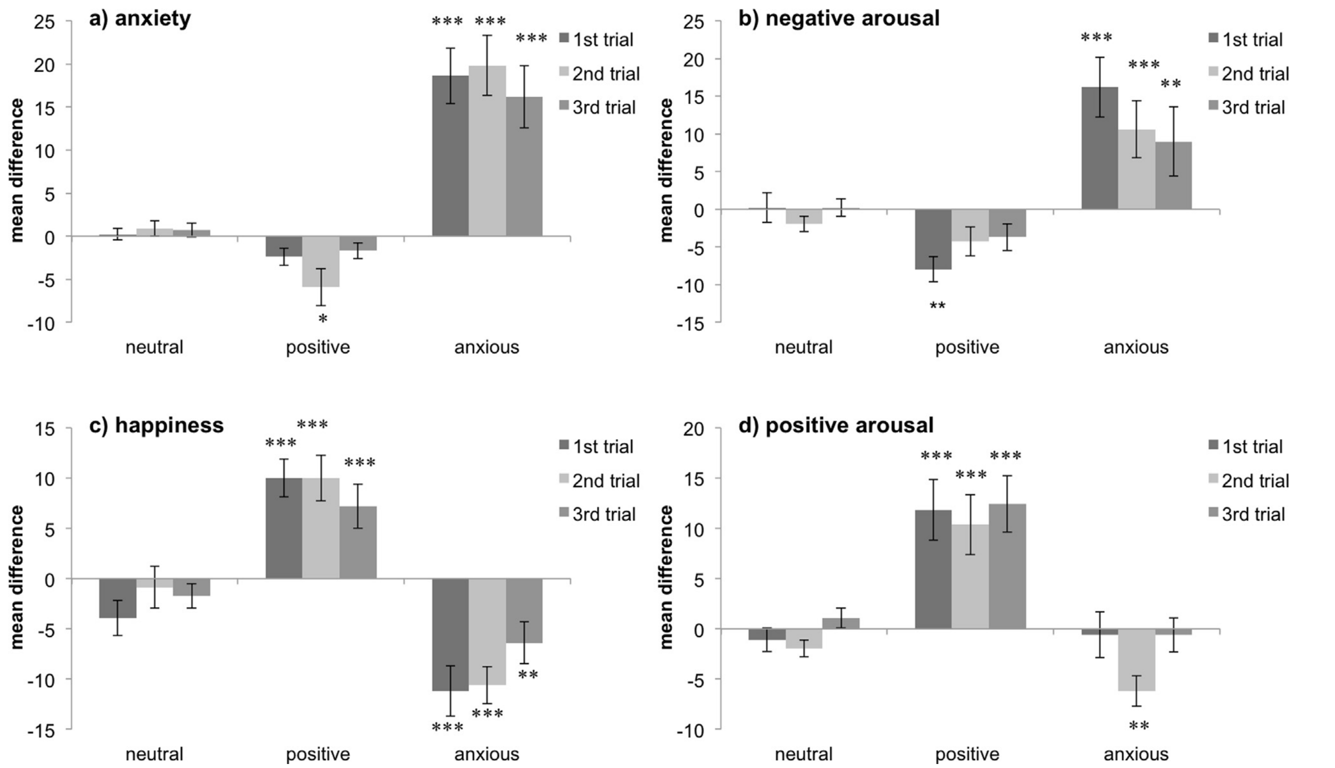

Fig. 2. Mean difference scores (post induction minus pre induction) in the three groups are displayed for the anxiety (a), negative arousal (b), happiness (c), and positive arousal (d) scales. Results showed successful emotional induction. * denotes significant changes from pre induction to post induction, with *** $p < 0.001$, ** $p < 0.01$, and * $p < 0.05$.

respect to the retrieval of "Scenario-unrelated memory" ($p > 0.05$). However, a trend towards a significant difference in the "Scenario-related memory" emerged ($\chi^2 = 5.963$, $p = 0.051$; Kruskal–Wallis test, Table 2), with lower performance scores for the anxious group as compared to both the neutral group ($z = -2.451$, $p = 0.014$; Mann–Whitney *U* test, Table 2) and positive group ($z = -1.496$, $p = 0.135$; Mann–Whitney *U* test, Table 2). Since the performance score for "Scenario-related memory" is based on the memory for different subcomponents of episodic memory (WHAT, WHERE, and WHEN) and the memory for scenario-related details, we analyzed whether significant between-group differences existed within these different components.

The performance in the event-related WHAT-WHERE category was significantly different between groups ($\chi^2 = 7.219$, $p = 0.027$; Kruskal–Wallis test). Pair-wise comparisons revealed that the memory for the spatial location of scenarios (WHAT-WHERE, event-related) was significantly decreased in the anxious group as compared to both the neutral ($z = -2.449$, $p = 0.014$; Mann–Whitney *U* test, Table 2) and the positive group ($z = -2.007$, $p = 0.045$). Hence, our results suggest that an anxious emotional activation was associated with a reduced capability to retrieve the spatial location of events.

Moreover, familiarity with the movies had no significant influence on the participants' episodic memory performance (neutral: all $p \geq 0.166$; positive: all $p \geq 0.245$; anxious: all $p \geq 0.081$).

We next analyzed whether the intensity of emotional activation (mean scores) and pre-test scores on negative emotional states of depression, anxiety, and stress were associated with performance in the episodic memory test. Significant correlations between "negative arousal" and "WHAT-WHEN" ($r = -0.254$, $p = 0.028$; Pearson correlation) and the "event-related WHAT-WHEN" ($r = -0.261$, $p = 0.024$) were found. Moreover, the "event-related WHAT-WHERE" was negatively associated with negative arousal ($r = -0.256$, $p = 0.026$), but positively associated with happiness ($r = 0.252$, $p = 0.029$). No other correlations attained statistical significance.

4. Discussion

We designed a VR-based memory task that was inspired by the WWW memory test for rats and mice [16–18]. Here, we studied the impact of a positive and/or a negative emotional activation on different aspects of episodic memory formation during the WWW memory task. After viewing an emotionally arousing video clip, participants were repeatedly exposed to VR apartments in which specific events took place. The events varied with respect to their content and spatial location across each of the walk-throughs. During an unexpected test for the episodic memories formed, participants were asked to report the details of unique events as well as to remember where and when these events occurred.

Our main finding was that the induction of an anxious emotional state prior to episodic memory encoding impaired memory formation during the WWW task. In particular, the induction of an anxious emotional state decreased the ability to retrieve the spatial context related to the specific events. Furthermore, a trend towards a poorer memory for the details associated with a specific event was found in the anxious state condition. However, neither the anxious nor the positive emotional state had a significant effect on the memory for the content of specific events or the memory for the details of the invariant background scene. Participants' self-evaluations of the degree of emotional arousal experienced suggest that the negative emotional film produced relatively high levels of negative arousal and anxiety. Most importantly, we found an inverse correlation between the level of negative arousal and performance scores in memory for the spatial context (i.e., "event-related WHAT-WHERE" memory). Taken together, these results indicate that a relatively strong emotional arousal prior to learning might hamper the memory for event-location associations, although it does not lead to overall changes in general memory processes.

Using a similar methodological approach, we have recently demonstrated an age-dependent decline in episodic memory performance in a test that measures the core components of an episodic memory (i.e., the memory for events and their spatial and temporal contexts, see Ref. [23]). Interestingly, the episodic memory deficits observed in aged participants were accompanied by lower trait anxiety scores [23]. Taken together with the results from the present study, such a pattern of findings is in accordance with the general idea of a nonlinear inverted U-shaped relationship between hippocampally mediated functions and the degree of arousal [30,41,42]. Thus, it might be assumed that episodic memory (as measured by means of what, where and when tasks) can be disrupted or enhanced depending on the level of arousal prior to learning. However, the results from the present study also imply that the influence of emotional arousal on episodic memory is complex and might affect different aspects of memory (e.g., content vs. spatiotemporal context memory) in a versatile manner.

In the present study, we focused on the effects of emotional arousal on episodic memories for what happened, where and when during the encoding stage. Future studies should address the question as to whether emotional states induced immediately after VR walk-throughs would disturb the consolidation of episodic memories. Furthermore, it remains to be explored whether state-dependent learning plays a role in our paradigm. It would thus be interesting to test whether the retrieval of episodic memories is enhanced by the additional induction of emotional arousal immediately before the episodic memory test. Another question worth investigating would be to evaluate whether congruent (positive–positive) or incongruent (positive–negative) emotional states during encoding and retrieval would affect episodic memory retrieval.

Previous human studies confirmed a detrimental effect of stress and/or emotional activation prior to learning on episodic memory performance [30,42]. However, those studies usually employed verbal learning tasks to assess episodic memory. A major limitation of these studies is that the paradigms used are not measuring core elements of episodic or even episodic-like memory in terms of a memory for what happened, where and when [3,4,7]. There are also some preliminary findings in the literature which suggest that emotional arousal might modulate the establishment of item-context associations in both directions [15,43]. For example, it was recently shown that the remembrance of items in conjunction with their spatial and temporal learning context is better for high-arousal relative to low-arousal items [15]. Similarly, Bisby and Burgess [43] studied the role of negative emotional activation on item memory and memory for item-context associations. They showed that an increase in negative affect induced by threat of shock had no effect on item memory but impaired the memory for the associated background context [43]. The finding by Bisby and Burgess is in line with our present results which suggest that an emotional activation prior to episodic memory formation does not hamper the memory for the event itself, but selectively affects the association of content with spatial context information. This could be due to (a) a detrimental effect on spatial memory formation (poor spatial memory formation) or (b) a deficit in the association or binding of event and spatial context information. Both deficits would appear as impairments in remembering the spatial context of events.

The present study is a modification and extension of episodic memory paradigms [22,23] which are based on the principles of the episodic-like memory task for rodents [16–18]. The impairment in episodic memory performance due to an anxious emotional state also affirms the findings from animal studies that used the WWW memory task. For instance, it was shown that stress caused by an intraperitoneal injection procedure impairs the formation of episodic-like memory in rats [18]. Most importantly, acute stress diminishes episodic-like memory in rats by affecting specifically the memory for object locations but not for other subcomponents, i.e., temporal-object associations (see Ref. [44]). The administration of cognitive enhancers including D-cycloserine (agonist of the glycine site of the NMDA receptor), SR140333 (neurokinin-1 receptor antagonist) or senktide (neurokinin-3 receptor agonist) can rescue stress-induced episodic-like memory deficits in rats and mice [18,19,45].

The prefrontal cortex and hippocampus are critical structures for the formation and retrieval of episodic memories in humans [46,47] and episodic-like memories in rodents [48,49]. The integration of multimodal information on what happened, where and when appears to be mediated by a circuit involving the prefrontal cortex and CA3 subregion of the hippocampus [50]. Lesions to the hippocampus and its substructures disrupt episodic-like memory formation [49,51–53]. The hippocampus receives strong reciprocal projections from the amygdala which might be responsible for the inverted U-shaped effect of emotional arousal on hippocampus-dependent memory processes [30]. It is possible that the negative emotional state of participants in this study differentially affected the encoding and retrieval of different subcomponents (the memory for what, where and when) of episodic memories (see Ref. [44]). Such an interaction of amygdala dependent activation and the memory for different aspects of specific events might be particularly interesting as far as clinical research is concerned. For example, the exposure to a traumatic event can lead to stress-related mnemonic symptoms which are characterized by both a stronger retrieval of some aspects regarding this experience but also a diminished retrieval of other aspects associated with this event (see Ref. [54]). Our findings might also explain the inconsistent findings in studies that investigated disorder-specific explicit memory bias in patients with anxiety and stress-related disorders (see reviews by Refs. [55,56]). Interestingly, using an incidental learning paradigm, during which subjects imagined scenes combining referents of learned words with themselves, Becker et al. [57,58] were able to show a disorder-specific explicit memory bias in patients with panic disorder.

It is well known that the recollection of past experiences as well as the anticipation of potential future events can affect patients' behavior and the responses to psychotherapeutic interventions [59]. A better understanding on how patients with emotional disorders deal with personal memories and store new episodic memories may aid in designing as well as implementing psychological treatment interventions. Interestingly, the use of WWW tasks has been increasingly acknowledged in the field of cognitive gerontology and neuropsychology [28,29]. For instance, it was shown that the performance of Alzheimer's patients in visuospatial VR memory tasks provides a direct link to patients' everyday memory complaints [29]. Thus, similar to studies in patients with neurodegenerative diseases, WWW tasks might be a more appropriate tool to systematically assess episodic memory changes for neutral and emotionally arousing events in patients with emotional disorders.

5. Conclusion

The findings from the present study underline the complex interaction of emotional arousal and multimodal episodic memory formation. Furthermore, the herein introduced paradigm might represent a new methodological approach to identify and understand episodic memory alterations in patients with mood and anxiety disorders and may help to explain inconsistencies of earlier research on memory biases in anxiety disorders [49].

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