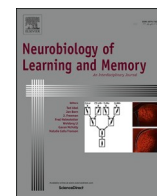




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## Impairment of aversive episodic memories during Covid-19 pandemic: The impact of emotional context on memory processes

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### ABSTRACT

The threatening context of the COVID-19 pandemic provided a unique setting to study the effects of negative psychological symptoms on memory processes. Episodic memory is an essential function of the human being related to the ability to store and remember experiences and anticipate possible events in the future. Studying this function in this context is crucial to understand what effects the pandemic will have on the formation of episodic memories. To study this, the formation of episodic memories was evaluated by free recall, recognition, and episode order tasks for an aversive and neutral content. The results indicated that aversive episodic memory is impaired both in the free recall task and in the recognition task. Even the beneficial effect that emotional memory usually has for the episodic order was undermined as there were no differences between the neutral and aversive condition. The present work adds to the evidence that indicates that the level of activation does not modify memory processes in a linear way, which also depends on the type of recall and the characteristics of the content to be encoded.

### 1. Introduction

During the 2020, when no efficient vaccines were available, nearly all countries imposed some level of quarantine to prevent the spreading of this disease. Hence, the economy was impaired, leading to a strong crisis that critically increased poverty in regions such as South America as well as globally (Buheji et al., 2020) negative impacting in psychological symptoms (Etchevers et al., 2021, Brooks et al., 2020). Specifically, levels of stress, anxiety and depression significantly increased in the population (Salari et al., 2020; Serafini et al., 2020; Johnson et al., 2020; Torrente et al., 2021). The outbreak of COVID-19 pandemic was considered as a particularly stressful event due to its novelty, the inability to premeditate, and the lack of vaccines for the cure (Vinkers et al., 2020), and it was also thought as a chronic stressor (Salari Nelson and Bergeman, 2020). In addition, investigations were carried out to

determine whether social isolation or "stay home" orders were associated with an increase in psychological symptoms (Jacobson et al., 2020). In turn, populations mental health deterioration, translated into an increased negative mental health symptom such as anxiety, stress, and depression that can modulate the encoding, consolidation, and retrieval of memories (Cahill & McGaugh, 1998, Beck & Clark, 1997, McGaugh et al., 1996, Roozendaal et al., 2009).

Episodic memory is a subtype of declarative memory, defined as the ability to remember where and when past events occurred (Tulving, 1972) and involves subjective consciousness (Wheeler et al., 1997). Furthermore, there is consensus that emotional episodic memories, whether they are pleasant or aversive events, are better remembered than neutral events (Hamann et al., 1999; Payne et al., 2006; Cahill & McGaugh, 1998; Reisberg & Heuer, 2004) proposing that emotional activation mediates episodic memory processes, and it serves as contextual cues for these

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memories (Damasio & Damasio, 1994; Damasio, 1999; Bechara et al., 2003; Allen et al., 2008). Moreover, emotion improves encoding as well as consolidation processes (LaBar & Cabeza, 2006; Dolcos et al., 2012). Other studies proposed that high emotional arousal could direct attention to prominent details while impairing memory of irrelevant ones (Easterbrook, 1959) and this narrowing of attention may prevent the encoding of relevant information for the memory of events, such as the face of a perpetrator during a crime (Christianson, 1992; Loftus et al., 1987; Kensinger, 2004). Regarding the ability to temporally order events, previous studies showed that emotional memories can be temporally ordered better than neutral memories (Schmidt et al., 2011), and among emotional memories those with negative valence are better remembered than the positive ones (D'Argembeau & Van der Linden, 2005). Considering that memories formed under high levels of stress are modified in their spatio-temporal organization (Payne et al., 2006; Brewin, 2007) and can cause a lack of order in mental experience (Bob & Fedor-Freybergh, 2008), it could be expected that the deeply threatening situation of the pandemic would modify the ability for temporal ordering.

Both depressive and anxious symptoms can modulate memory processes (Lachman & Agrigoroaei, 2012; Zlomuzica et al., 2014; Zaheed et al., 2020). Anxiety is a psychological and physiological state that can be a normal response to a stressful moment (Stein & Steckler, 2010), but when that stressful exposure is prolonged, the perceived stress levels can lead to appearance of anxiety disorders, as has been observed during the COVID-19 pandemic (Salari Nelson & Bergeman, 2020). Studies have found that stress significantly correlates with anxiety levels (Racic et al., 2017), and an onset of state anxiety has even been proposed as the first psychological response to stress (Boudarene et al., 2002). Moreover, the relationship between stress and anxiety has been shown to be mediated by age, the quality of sleep and loneliness during the Covid-19 pandemic in young adults (Varma et al., 2021; Rossell et al., 2021). While, on the other hand, it was observed that perceived stress was a common contributor for anxiety and depressive disorders in all age groups (Moreno et al., 2020). On the one hand, it was observed that people with anxiety disorders obtained worse performances than healthy subjects in episodic memory tasks, particularly in the encoding phase, and this impairment is observed even in neutral or irrelevant content (Airaksinen et al., 2005). For the retrieval, literature generally indicates that this process contains a bias towards negative content (Zlomuzica et al., 2014). On the other hand, the relationship between depression and various cognitive deficits have been widely studied, and it was observed that the impaired domains were working memory, inhibitory control, episodic memory, and speed processing (Airaksinen et al., 2004; Bora, et al., 2013; Gotlib & Joormann, 2010).

The encoding of episodic memories is dependent on the emotional context in which it occurs, and different effects were found according to the content of the learned material (Erk et al., 2003). Thus, the COVID-19 pandemic offers a unique scenario to study how the episodic memories are formed under very demanding psychological conditions.

Regarding the effect of stress, Schwabe et al. (2012) propose an integral model in which the different phases of memory are affected in a differential way: encoding and consolidation of memories are favored, while retrieval is impaired. Previous studies evaluated the effect of stress generated by a threatening social situation on a non-emotional declarative task. The results indicated that social stress not only improved the encoding but also the persistence of the neutral memory (Fernández et al., 2015). Similar results in this line were found in paradigms that induced stress by cold pressor Test (CPT) (Schwabe et al., 2008). However, other studies observed that high stress levels often impair neutral memories, while typically enhancing emotional memories (Buchanan & Lovallo, 2001; Cahill et al., 2003; McGaugh, 2000). In addition, Payne et al. (2007) observed that learning under conditions of previous stress improved consolidation of emotional content while impaired neutral content (Payne et al., 2007). Other studies proposed that stress followed by a subsequent sleep cycle interacts to promote the consolidation of prominent memories (Kim & Payne, 2020).

We hypothesize that the increase in the values of negative psychological symptoms, such as depressive mood and anxiety, due to the context of the COVID-19 pandemic, modifies the ability to encode and consolidate memories. Thus, we expect that the advantage of emotional episodic memories over neutral ones would be lost not only for the content but also for the temporal order information.

To evaluate this, participants learned an emotional or neutral story on day 1 and were immediately asked for a free recall. On day 8 (one week later) they were tested for free recall, recognition, and temporal order of the events. Six months later, the same procedure was applied but rotating the content of the stories between groups.

## 2. Materials and methods

### 2.1. Participants

101 residents of the Metropolitan Area of Buenos Aires, Argentina participated in the study. The sample size was decided according to previous studies sharing similar designs (Wang et al., 2021). They were recruited through advertisements on social networks. Prior to their participation, they signed an informed consent approved by the Alberto Taquini Biomedical Research Ethics Committee. Their ages ranged from 18 to 40 years ( $25.69 \pm 4.36$ ), they did not consume psychotropic drugs and they were not suffering from psychiatric disorders at the time of the experiment. All experiments were carried out on online platforms. The first round was carried out in April of 2020, within the first month of the period of the Preventive and Mandatory Social Isolation (ASPO) by COVID-19 and the second was carried out in October (6 months later) but within the same quarantine process. 101 subjects participated in the initial round, 10 of whom decided not to participate in the second round. Therefore, the final number of participants was 91 (Table 1).

### 2.2. Experimental design

The subjects participated in two different rounds of data collection separated by 6 months. Each participant was randomly assigned to the experimental conditions of the first round. These conditions were formed according to the emotional content of the video that they observed in the training phase, which could be aversive or neutral. The "Aversive" condition was formed of 47 subjects (32 women, 15 men; mean age  $\pm$  SD:  $26.85 \pm 4.80$ ) and the neutral condition was formed of 44 subjects (30 women, 14 men; mean age  $\pm$  SD:  $24.45 \pm 3.48$ ). About 6 months later, still within the quarantine period, each participant was assigned to the other experimental condition, e.g. The participants watching the aversive story now watched the neutral one, and the same applied to the other group of subjects.

### 2.3. Procedure

The experiment was carried out between 10 a.m. and 5 p.m. First, participants received a link via email to complete the sociodemographic

**Table 1**

Sociodemographic data. Number of participants in each group, mean age  $\pm$  SD, percentage of different genders and education level. Participants in the aversive condition of round 1 then became part of the neutral condition in round 2, and vice versa.

		Aversive-round 1 Neutral-round 2	Neutral-round 1 Aversive-round 2
	<b>N</b>	47	44
	<b>Age</b>	$26.85 \pm 4.80$	$24.45 \pm 3.48$
<b>Gender</b>	Males	31.91% (15)	31.81% (14)
	Females	70.21% (33)	68.18% (30)
<b>Education</b>	High school graduates	21.28% (10)	6.82% (3)
	College students	48.94% (23)	56.82% (25)
	College graduates	29.79% (14)	36.36% (16)

questionnaire, the self-administered symptomatology scales: Beck Depression Inventory-II (Beck et al., 1996) and State Trait Anxiety Inventory (Spielberger, 2010). After that, they received a link for the video call and the entire experiment was conducted by one experimenter using this system. Once the connection was established, participants were asked to turn the volume up to maximum and pay attention to the screen. After that, the experimenter's screen was shared, and the video played. Previously, they were advised that if they had any connection problems during the video, they should notify the experimenter. Nevertheless, this situation did not happen. Immediately after the video, participants performed the short-term free recall. One week later, at the same time as day 1, participants entered a video call link previously sent via email. First, they performed the long-term free recall and then the recognition task. It is important to mention that, except when completing the forms, the experimenter was present and available in the video call throughout the experiment. The procedure was repeated in the same way 6 months later, alternating the content of the stories among the participants (that is, the participants who first saw the aversive video later saw the neutral one and vice versa) (Fig. 1).

#### 2.4. Sociodemographic questionnaire

This questionnaire consisted of answering questions about age, gender, place of residence during quarantine, chronic medication, and psychiatric disorders.

#### 2.5. Symptomatology scales

Self-administered depression scale Beck Depression Inventory-II

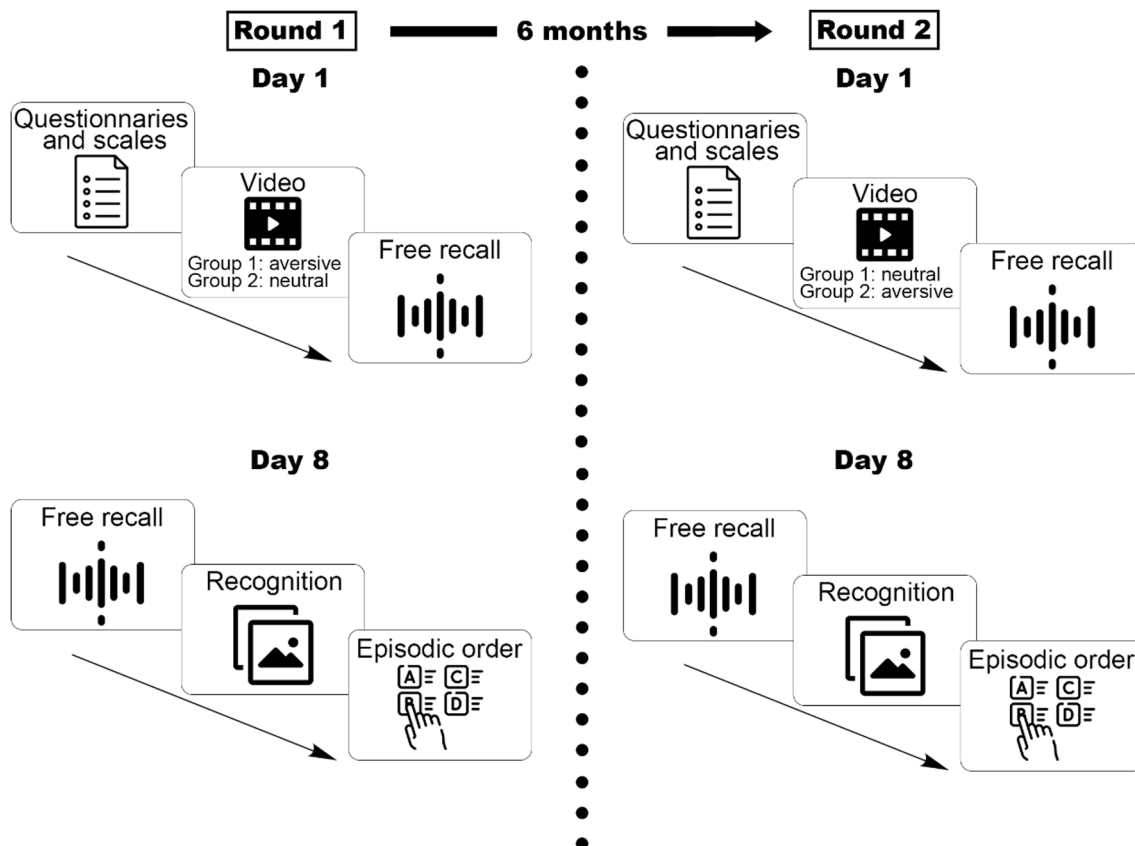
(Beck et al., 1996) and anxiety scale State Trait Anxiety Inventory (Spielberger, 2010).

#### 2.6. Episodic stories

The episodic stories all consisted of a 3-min video composed of 11 still photographs, each of them was presented on the screen for 15 s while an auditory narrative was being played describing the story. The story with aversive emotional content showed a person who suffered from a traffic accident and died in the end. The emotionally neutral story depicted a person's daily routine. These stimuli were controlled with an independent sample of subjects, who were asked to indicate whether the stimulus was negative, neutral, or positive. 15 additional subjects rated the aversive video and 14 the neutral one. A continuous bar was used that ranged from  $-100$  to  $-30$  for negativity, from  $-30$  to  $+30$  for neutrality and from  $+30$  to  $+100$  for positivity. The participants were asked to choose the value that in their opinion best represented the stimulus (Aversive:  $-54.00 \pm 30.18$ , Neutral:  $11.14 \pm 20.91$ ,  $t(27) = 6.70$ ,  $p < 0.001$ ).

#### 2.7. Free recall

On Day 1, participants were asked to orally recall the content of the video immediately after watching the video. All oral reports were recorded, and then the number of correct and false details were counted. Absolute number of reported details about the actions, people, objects, and elements of the environment provided were counted as the subject's memory performance. It is important to emphasize that only the remembered details of the oral episodic story were counted for this



**Fig. 1.** Experimental procedure. The procedure was divided into two parts: First, in round 1 the participants completed day 1 and day 8 both at the same time of day but with a week of difference. One group watched the aversive video, and another group watched the neutral one. After about 6 months, round 2 was carried out. The procedure was the same, but the content of the videos was alternated. At the end of the experiment, the participants had watched an aversive video and a neutral video with 6 months between one round and the other. Icons "Choose", "Archivos", "Radio-wave", "Video-player" and "image" made by Freepik [https://www.flaticon.com/authors/freepik] from www.flaticon.com.

analysis, therefore, to decide whether the remembered detail was true or false, the story provided by the subject was compared with the original oral story of the video. Each detail or its synonyms was counted only once, no matter how many times it was repeated in the free recall. The instruction was “Now I am going to ask you to describe to me, in as much detail as possible, what happened in the video. You have no time limit to perform it, do it on your time.”

The same procedure was conducted again on Day 8 as the delayed recall.

## 2.8. Recognition task

The recognition task consisted of 11 images that were presented altogether, in which 5 of them were already presented in the video of the training session (day 1) and 6 were new. These 6 new photos were similar in content to the ones shown in the story. Three of them shared similar elements to 3 photos that were shown both in the story and later presented in the recognition task (e.g., in the story there was a photo of a work meeting. In the recognition task there were both that photo and a new photo with another work meeting). The other 3 new photos had similar elements to 3 photos shown in the story, but then were absent in the recognition task (e.g., In the story there was a photo of a bar. In the following recognition task, this photo was absent, but another photo with a new bar was presented). Participants had to choose among all these images, which they considered to have seen in the video. After that, they had to arrange them according to the original episodic order of the story (temporal order memory). The participants had no time limit for the whole recall test. Their answers were registered and were offline scored by experimenters. For the temporal order, deviations were accounted for analysis, and this was done by comparing it with the correct episodic order of the story. If the participants chose an incorrect photo but placed the event in the correct place in the episodic order, it was taken as valid, since in this task only the episodic order of events was evaluated.

## 2.9. Statistical analysis

The analyzes were carried out in the statistical software IBM SPSS Statistics 25. The scores of the symptomatology scales (STAI and BDI) were used as total values, i.e., the values obtained by the subjects in each test according to the correction rules proposed by each test.

First, with the aim of evaluating whether the values on these scales were increased in relation to a normal context (before the pandemic), the values obtained by the subjects in both rounds were contrasted with the values of the validations of the symptomatology scales made in the Argentine population by One Sample *t*-test of each of the variables. These validations were carried out in a population like the current sample in terms of place of origin, educational level, age, and gender (Bonicatto et al., 1998; Leibovich de Figueroa, 1991). The values obtained in the symptomatology scales were compared between the two experimental conditions by *t*-test in each round. Also, it was analyzed that the aversive condition of round 1 did not have differences with the aversive condition of round 2 by *t*-test, and the same was done for the neutral condition.

As each story had a different total of possible correct details to be remembered (Aversive story: 132, Neutral story: 124), we normalized the true recalled details using the percentage of true details (i.e.,  $N^\circ$  of correct details/possible correct details\*100) and we analyzed it with repeated measures ANOVAs with “time” as an intra-subject factor with two levels (day 1, day 8), “round” and “conditions” as inter-subject factors with two levels each (round 1, round 2 and aversive, neutral, respectively). The second round was considered independent of the first one to run the ANOVA. We performed the same analysis for the number of false details however, after significant interaction simple effects analyses were performed.

Moreover, in relation to the recognition task, both the number of

correct and incorrect choices were counted. Regarding the episodic order task, the number of deviations with respect to the correct temporal order was registered. These variables were analyzed with ANOVAs with “round” and “condition” as inter-subjects’ factors, with two levels each (round 1, round 2 and aversive, neutral, respectively). After significant interaction simple effects analyses were performed. The second round was considered independent of the first one to run the ANOVAs.

Finally, to examine whether the encoding and consolidation processes could be related by negative psychological symptoms, we analyzed the values obtained on the symptomatology scales and the performance obtained in each task by both conditions with Pearson correlations. For state anxiety, partial correlations were carried out between state anxiety and the recall variables, controlling for trait anxiety, since the previous literature indicates that this variable could account for the baseline anxiety of the population outside the influence of the pandemic (Chen et al., 2021).

Alpha was set at 0.05. For the correlation analyses we did not perform corrections for multiple correlations.

## 3. Results

### 3.1. Symptomatology scales

Regarding the levels of state anxiety, trait anxiety and depression of the aversive and neutral conditions we found a significant increase during the quarantine by COVID-19 compared to the mean level of the Argentinean population (mean values of the validation scales) before the quarantine (Table 1. [Supplementary material](#)). We further found no significant differences for the symptomatology scales neither between the two rounds of data collection (month 1 and month 6) (Table 2. [Supplementary material](#)) nor between the rounds in each condition (neutral or aversive content) for these same variables (Table 3. [Supplementary material](#)). Taken together, these results indicate that the values obtained in the symptomatology scales were higher at the first month of quarantine than the norm, and it remained high after 6 months.

### 3.2. Episodic memory tasks

#### 3.2.1. Correct details

The aversive condition performed significantly worse than neutral condition [ $F_{\text{condition}}(1,178) = 17.243, p < 0.0001$ ], there was a significant memory decay between day 1 and day 8 [ $F_{\text{time}}(1,178) = 222.622, p < 0.0001$ ] but there was no significant effect of rounds [ $F_{\text{round}}(1,178) = 0.229, p = 0.633$ ]. There were no significant interactions [ $F_{\text{time*round*condition}}(1,178) = 2.516, p = 0.114$ ;  $F_{\text{time*condition}}(1,178) = 0.017, p = 0.896$ ;  $F_{\text{time*round}}(1,178) = 3.469, p = 0.064$ ;  $F_{\text{round*condition}}(1,178) = 1.771, p = 0.185$ ]. As there were no significant interactions, the results of the two rounds are shown pooled (Fig. 2A).

#### 3.2.2. False details

There was neither significant time\*round\*condition interaction [ $F_{\text{time*round*condition}}(1,178) = 1.468, p = 0.227$ ] nor time\*condition interaction [ $F_{\text{time*condition}}(1,178) = 0.592, p = 0.443$ ]. However, there were significant time\*round [ $F_{\text{time*round}}(1,178) = 9.692, p = 0.002$ ] and round\*condition interactions [ $F_{\text{round*condition}}(1,178) = 12.936, p < 0.001$ ]. Thus, we performed simple effect analysis. We observed that for the first round there was no significant differences between conditions [ $F_{\text{condition}}(1,178) = 3.227, p = 0.074$ ], however, for the second round the aversive condition showed significantly higher false details than the neutral [ $F_{\text{condition}}(1,178) = 10.825, p = 0.001$ ]. Furthermore, for the aversive condition there was no significant differences between rounds [ $F_{\text{round}}(1,178) = 0.480, p = 0.489$ ] but the neutral condition showed significantly more false details in the first round than in the second one [ $F_{\text{round}}(1,178) = 19.307, p < 0.001$ ]. There were no significant differences on day 1 between rounds [ $F_{\text{time}}(1,178) = 0.204, p = 0.752$ ] but on

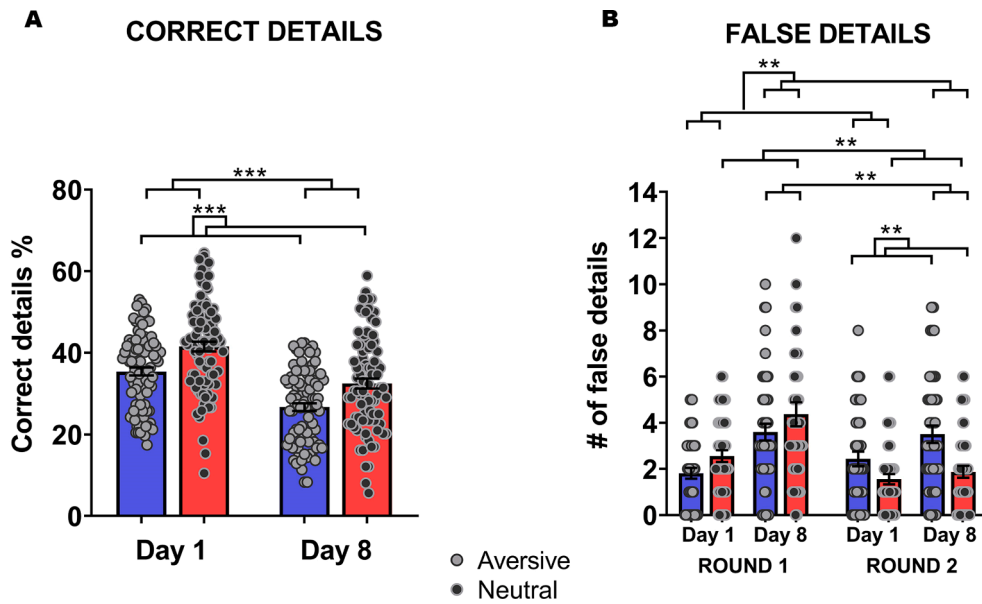


Fig. 2. Free recall. A. Percentage of correct details on day 1 and 8 ± SEM. The two rounds are shown pooled. B. Number of false details on day 1 and 8 ± SEM. \*\*,  $p < 0.01$ ; \*\*\*,  $p < 0.001$ .

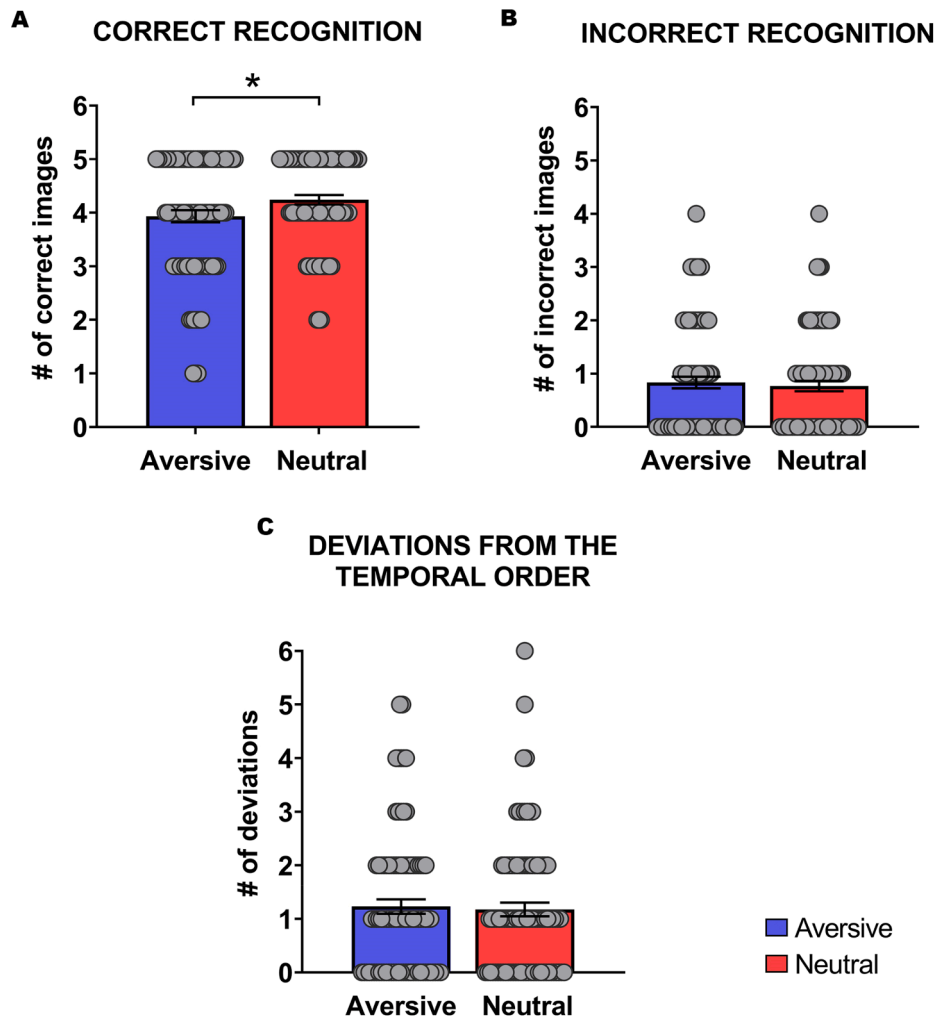


Fig. 3. Recognition and episodic order. A. Number of correct images chosen ± SD. B. Number of incorrect images chosen ± SD. C. Deviations from the correct episodic order ± SD. \*,  $p < 0.05$ . The two rounds are shown pooled.

day 8 there were significantly more false details on the second round [ $F_{\text{time}}(1,178) = 11.134, p = 0.001$ ]. Moreover, for both rounds there was a significant increase in false memory details from day 1 to day 8 [ $F_{\text{round1}}(1,178) = 48.959, p < 0.001$ ;  $F_{\text{round2}}(1,178) = 6.730, p = 0.10$ ] (Fig. 2B).

### 3.3. Recognition

The aversive condition performed significantly worse than the neutral condition for correct choices [ $F_{\text{condition}}(1,178) = 4.443, p = 0.03$ ], while there was no significant effect of rounds [ $F_{\text{round}}(1,178) = 1.338, p = 0.24$ ]. Moreover, there was no significant interactions between rounds and conditions [ $F_{\text{round*condition}}(1,178) = 0.775, p = 0.38$ ]. As there was no significant interaction the results of the two rounds are shown pooled (Fig. 3A).

For the incorrect choices there was a significant round\*condition interaction [ $F_{\text{round*condition}}(1,178) = 4.90, p = 0.02$ ]. However, when simple effects analyses were performed, there were no significant differences between the variables [ $F_{\text{round1}}(1,178) = 3.57, p = 0.06$ ;  $F_{\text{round2}}(1,178) = 1.540, p = 0.21$ ;  $F_{\text{aversive}}(1,178) = 2.09, p = 0.14$ ;  $F_{\text{neutral}}(1,178) = 2.83, p = 0.09$ ] (Fig. 3B).

### 3.4. Temporal order

For the deviations from the episodic order there were no significant differences between conditions [ $F_{\text{condition}}(1,178) = 0.08, p = 0.77$ ] and there was no significant effect of rounds [ $F_{\text{round}}(1,178) = 0.02, p = 0.86$ ]. Moreover, there was no significant round\*condition interaction

[ $F_{\text{round*condition}}(1,178) = 1.163, p = 0.28$ ] (Fig. 3C).

### 3.5. Symptomatology scales and memory variables

#### 3.5.1. Symptomatology scales and free recall

Since negative psychological symptoms modulate the memory processes, we further performed correlations analyses between the symptomatology scales values obtained and the values obtained in the free recall (day 1 and day 8) of each condition. First, we ran partial correlations between state anxiety and the recall variables, controlling for trait anxiety. We found a significant negative correlation between state anxiety and correct details on day 1 for the aversive condition ( $r = -0.27, p = 0.009$ ), while this result was not observed in the neutral one ( $r = -0.03, p = 0.74$ , Fig. 4). In contrast, on day 8, we did not observe significant negative correlations between anxiety levels in either condition (Aversive:  $r = -0.19, p = 0.07$ ; Neutral:  $r = -0.16, p = 0.12$ ). Regarding depression, no significant correlations were found between this variable and correct details on day 8 for any of the conditions (Aversive:  $r = -0.12, p = 0.22$ ; Neutral:  $r = -0.16, p = 0.12$ ). Overall, these results indicate that the higher the anxiety on day 1, the worse the performance in learning the aversive content. In this way, it seems that the encoding of aversive content is more affected by the state anxiety than the neutral one, while consolidation and retrieval seem not to be affected.

Regarding false details, the significant interactions that were found did not allow correlations to be made with the pooled data. For this reason, correlations were made between symptomatology and memory variables for each round separately. We found a significant negative

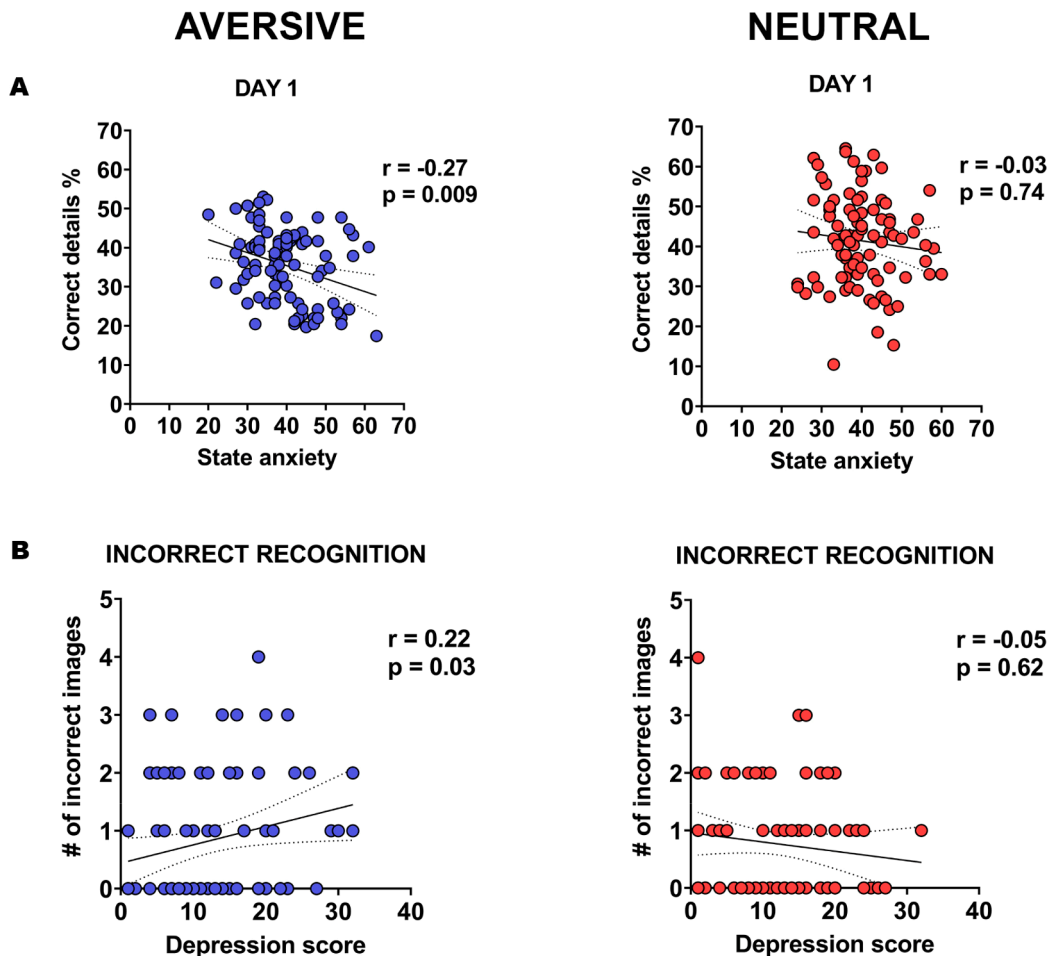


Fig. 4. Symptomatology scores and episodic memory performance. A. Partial correlations of both conditions between state anxiety and correct details on day 1, controlling for trait anxiety. B. Correlations between depression score and incorrect recognition. The two rounds are shown pooled.

correlation between depression and false details on day 8 for the neutral condition, in the first round (Aversive:  $r = 0.07$ ,  $p = 0.62$ ; Neutral:  $r = 0.31$ ,  $p = 0.03$ ). No other significant correlation was found ( $-0.17 < r < 0.26$ , all  $ps > 0.06$ ).

### 3.5.2. Symptomatology scales and recognition task

We then evaluated the relationship between the values obtained in the symptomatology scales and the measures obtained both in the recognition task and episodic order task. We found a significant positive correlation between the values obtained on the depression scale and the number of incorrect choices for the aversive condition ( $r = 0.22$ ,  $p = 0.03$ ). However, no significant correlation was found for the neutral condition ( $r = -0.05$ ,  $p = 0.62$ ). No other significant correlations were found ( $-0.27 < r < 0.26$ , all  $ps > 0.05$ ).

## 4. Discussion

Here we show that, contrary to our hypothesis, the aversive condition scored worse on the correct details in both the short-term and long-term evaluation. Furthermore, the aversive content was recognized less than the neutral content and no differences were observed between the conditions in the temporal order task, that is, the effect of improving emotion in the temporal order ability was lost. In addition, we observed for the aversive condition that the higher the level of anxiety the lower the percentage of correct details on day 1 and the higher the level of depression the higher the number of incorrect images selected in the recognition task on day 8. Furthermore, we found that both anxiety and depression values increased compared to population values prior to the pandemic context. Thus, we suggest that the pandemic context, translated into increases in anxiety and depression, could be responsible for decreased performance in aversive content.

Though, the general literature indicates that emotional episodic memories are better remembered than neutral ones and these effects were observed in different types of recall: free recall (Cahill et al., 1996), recognition (Bradley et al., 1992) or temporal order tasks (Groch et al., 2011; Petrucci & Palombo, 2021).

A possible explanation for these apparently contradictory results could be the Yerkes-Dodson curve (Yerkes & Dodson, 1908). This phenomenon has broad evidence, and it states that there is an optimal point of activation where the cognitive performance seems to be strengthened, whereas if the activation is too low or too high this effect disappears. Moreover, if the activation level is too high (e.g., by strong stress or anxiety) the memory recall performance was impaired. In our results, the COVID-19 pandemic could have caused high levels of activation impairing the aversive content, leading to not only losing the beneficial effect of emotion but also being diminished compared to non-emotional content (Yerkes & Dodson, 1908; Mair et al., 2011).

Three main brain regions have been proposed to be involved in the emotion enhancement effect in episodic memory (Maratos et al., 2001): areas of the amygdala, the hippocampus that contribute to the encoding, consolidation, and retrieval of emotional memories (Kensinger & Corkin, 2004; McGaugh, 2004; Ritchey et al., 2008; Kensinger & Schacter, 2005), and the prefrontal cortex (PFC) that benefits executive, attentional, and semantic processes (Dolcos et al., 2017). However, it has been proposed that at the high end of the Yerkes Dodson curve, where the individual is suffering high levels of psychological demand, the function of the PFC could be suppressed for excessive emotionality (Diamond et al., 2007). In addition, the involvement or not of the prefrontal cortex has been thought as a delimiter between simple and complex tasks, and in turn it has been observed that memory tasks that present the curvilinear relationship of the Yerkes Dodson curve between activation and performance are precisely those that involve this brain area (Diamond et al., 2007). Also, in lesion and neuroimaging studies of the PFC, complex tasks such as those involving free recall without cues were particularly affected compared with simple recognition tasks that involve yes-no responses (Ranganath et al., 2003; Ranganath & Knight

2005). Taken together, we propose that the increased levels of anxiety and depression due to the COVID-19 pandemic could have increased the cognitive activation from its optimal level, hence impairing the encoding of new episodic memory.

Besides, the effects of anxiety and depression on memory processes could be related to changes in attention ability that affect memory encoding. Anxiety modulates the functioning of attention, and particularly, state anxiety was associated with the attentional networks improving the receptivity based on the salience and relevance of the stimuli (Pacheco-Unguetti et al., 2010). However, our results showed that the salient material was not the better remembered in the free recall task. But we did find a significant negative correlation between state anxiety and correct details for the aversive condition at the encoding phase. Thus, we suggest that the later memory differences between two conditions could be due to the anxiety states at memory encoding.

Additionally, the fact that neutral content was better encoded than aversive could be explained by the possible lack of novelty of the aversive stimulus, that is, receiving information about an accident that produces a death may be encoded as a non-novel memory when the news about deaths or possible deaths are present constantly in everyday life. In this way, it could be relatively easy to process this type of information due to its familiarity component (Waris et al., 2021).

As previously noted, the level of activation distinctively affects types of retrieval: while free recall tasks can be impaired, recognition tasks may not be affected, and this was due to differences in difficulty related to the availability of retrieval cues (Gagnon & Wagner, 2016). However, our results indicate that although the aversive condition did not present more incorrect choices, it chose significantly fewer correct images than the neutral condition. This could be indicating a comprehensive modification in the way of encoding aversive memories that affects both types of recall, regardless of the difficulty of the task. Nevertheless, more studies are needed to compare both types of recall in the context of a pandemic depending on the memory type. Even in the future, the effect of remembering traumatic memories specifically happened during the COVID-19 pandemic should be highly interesting.

Cognitive distortions have been raised as responsible for several mental disorders such as depression, anxiety, chronic pain, substance abuse, among others (Li & Wang, 2013). In addition, previous studies showed mixed effects regarding how distorted view of the world can modulate episodic memories in depression and/or anxiety populations. For example, people with anxiety disorders codified episodic memories worse than healthy subjects (Airaksinen et al., 2005). Nonetheless, patients with generalized anxiety disorder showed memory biases for threat information that was in line with their worries (Coles et al., 2007; Friedman et al., 2000). Similarly, patients that suffer from social phobia or panic disorder showed self-threat-relevant memory biases in retrieving auto-biographical memories (Wenzel & Cochran, 2006). Thus, according to this, if the information provided in our negative story had been aligned with the participants main source of worries (i.e., pandemic related content) we could have found the enhancement that is generally observed for the emotional memories. In addition, there is a type of cognitive distortion that occurs in these depressive or anxious moods called selective abstraction and it is related to paying attention only to the negative aspects, ignoring the positive things (Deperrois & Combalbert, 2021). Thus, individuals with high depressive symptoms tend to process information in a biased way focusing on negative and violent elements leading to the reaffirmation of their own negative perception of reality (Watkins et al., 1996). Depressed subjects have more robust and persistent memories of negative events, and positive memories are more easily forgotten (Gotlib & Joormann, 2010). However, our results indicate that the higher the level of depression the higher the number of incorrect choices in the aversive condition at the recognition task. Besides, depression can enhance the specificity of negative memories (Leal et al., 2014). Although, the neutral condition reached more significant correct choices at the recognition task. A possible explanation for these contradictory results is that the pandemic



context decreases the impact of the aversive story, and it does not reach the level of emotional awareness that it should, whereas in a context before the pandemic, the negative information could have been better remembered by subjects with depressive symptoms.

Regarding false memory, there was a significant increase in false details between day 1 and day 8, regardless of round or condition. A considerable body of evidence had shown that memories, in addition to being lost, can become increasingly distorted over time (Payne et al., 1996; Seamon et al., 2002), and the probability of generating false memories augment as the delay increases (McDermott, 1996). Furthermore, in the second round the aversive condition presented significantly more false details than the neutral one. This result contradicts with previous studies in which the neutral false memory rate was higher than emotional false memory independent of the memory phase (Smeets et al., 2008). This could be related to the possible lack of salience of our aversive stimulus compared to the threatening context of the pandemic, but the difference was not observed in round 1. The differences between rounds could be explained by uncontrolled variables that can increase the formation of false memories such as personality, intelligence, perception abilities or predisposition to dissociative experience (Zhu et al., 2010). Moreover, we found a significant positive correlation at round 1 between depression and false details on day 8 for the neutral condition. The literature showed mixed results regarding how the depressive mood affects the formation of false memories. For example, in subjects with Post Traumatic Stress Disorder, a positive correlation between depression and false memories was observed (Zoellner et al., 2000), while this relationship was absent using a non-clinical sample (Salthouse & Siedlecki, 2007), and it was even seen that negative mood was related to fewer false memories (Storbeck & Clore, 2005).

The main limitation of this work is the impossibility of comparing the measurements obtained by the subjects with those obtained outside the context of the pandemic. However, we compared the values obtained in the psychological variables with the population means and observed that the levels of anxiety and depression were significantly increased with respect to the population mean before the COVID-19 pandemic. These results coincide with large-scale surveys of the Argentine population during the pandemic, which indicate a significant increase in anxiety and depressive symptoms even in the early stages of the pandemic, in people who had never presented these symptoms (Torrente et al., 2021). Further, we carried out correlations between state anxiety and memory variables controlling for trait anxiety that was previously observed as a useful measure of baseline anxiety outside the pandemic (Chen et al., 2021). Given that trait anxiety is a proxy for the dispositional tendency to experience greater anxiety in response to stress and threat (Chen et al., 2021), the correlations that prevailed controlling trait anxiety suggest that the impact on memory is related to the stress caused by the COVID-19 pandemic.

Finally, it would have been desirable to have a physiological measure of people's stress (for example blood or saliva cortisol measurements), but this was impossible due to the obligation to carry out the experiments virtually. However, we obtained measures of anxiety, previously defined as the psychophysiological signal that the stress response has been initiated (Robinson, 1990). Last but not the least, we did not have a post-event emotional rating scale which indicates the emotional state was indeed caused by the COVID-19 stimulus. However, the negativity or neutrality of the stories was controlled with an independent group of participants and both stories served their purpose.

In the end, the present research contributed to the field in the following aspects. First, our results add to the increasing evidence that human basic cognitive function was negatively affected by the COVID-19 pandemic context. Second, we provided novel evidence that episodic memories attached with different emotional content are affected differently from the context before the COVID-19 pandemic. Last but not the least, considering that episodic memory is the ability to recall information about what happened, where it happened, and when the event happened (Tulving, 1993) and is a central function for the

everyday life, our study can provide information for future psychological treatments that address, for example, Post-Traumatic Stress Disorders (PTSD) related to the pandemic that are already foreseen (Kathirvel, 2020; Carmassi et al., 2020), or simply to understand how the formation of memory of events works in highly demanding environments.

## Author contributions

CSL, MB, FAUB, JW and CF made substantial contributions to the conception and design of the work. CSL and MB ran the experiments. CSL and MB performed the statistical analyses. CSL and CF contributed by drafting the work. CLS, MB, FAUB, BIL, JW and CF contributed to revising it critically.

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The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript. The authors have declared that no competing interests exist.

## Data availability

The raw data supporting the conclusions of this article can be found in: <https://zenodo.org/record/5809398>.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Appendix A. Supplementary material

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.nlm.2021.107575>.

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