



False recognitions in the DRM paradigm: the role of stress and warning

Melike Guzey¹ · Banu Yılmaz²

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Abstract

For the last decades, the factors increasing or decreasing the frequency of false memories have been of great interest. Some research also examined the effect of stress and warning on the true and false recognitions; however, so far most of the studies have yielded contradictory results or seems inadequate to understand the effect of these factors on false memory phenomenon. The purpose of this study is to examine the joint effects of stress and warning on the frequency of false and true memories elicited by the list-learning paradigm. The word lists derived from the Deese–Roediger–McDermott (DRM) paradigm were used in order to measure false and true recognition rates. Participants (N = 126) were exposed to either the Trier Social Stress Test (a stress condition) or a filler task at the beginning of the experiment (no-stress condition). Then, they were either subjected to a warning about false memories before DRM (pre-warning condition), subjected to a warning about false memories after DRM (post-warning condition), or given no warning at all (no-warning condition). Results showed that stress had a statistically significant effect on true recognition but not on false recognition. Furthermore, warning given after the DRM lists had a decreasing effect on the frequency of false memories. No significant interaction effect between stress and warning was found. Although our hypotheses were not confirmed, this study can contribute to the existing body of research by providing evidence that stress and warning have differential effects on both true and false memories derived from the DRM paradigm.

Keywords DRM paradigm · Stress · Warning · False memory · True memory

Introduction

Although memory is considered as widely accurate, a considerable amount of research has pointed out the fallibility of human memory, which is referred to as false memories (Roediger & McDermott 1995). The Deese–Roediger–McDermott (DRM) paradigm is one of the most widely used methods to elicit false memories in a controlled laboratory setting. In their original study, Roediger and McDermott (1995) suggested that false memories have arisen from the activation of implicit associative processes and misattribution of items

to sources other than original. The DRM paradigm, reestablished by Deese's (1959) list-learning paradigm, implies the idea that false memories result from unconscious associative processes of word lists to non-presented word lures during encoding (Roediger & McDermott, 1995). In other words, if a number of words in a list are all associated with a non-presented word lure, in the recall or recognition phase false alarm rate for this critical lure is expected to be very high. In this regard, in the DRM paradigm, participants are presented word lists semantically associated with a non-presented critical lure. After the presentation of word lists, participants are given a recognition or recall test. Original research demonstrated that both recall and recognition rates of non-presented critical lures were found to be as high as of studied words (Roediger & McDermott 1995).

Since Roediger and McDermott's (1995) pioneer study, a large scale of research has been conducted to understand the false memories derived by the DRM paradigm. Given that false memories may cause problems related to legal or clinical areas, one major issue has been to determine the factors playing a role in the formation of false memories

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✉ Melike Guzey
melikeguzey@gmail.com

¹ Department of Psychology, Faculty of Language, History and Geography, Ankara University, Sıhhiye, 06100 Ankara, Turkey

² Ankara, Turkey

and how to attenuate these false memories. Extant research tested several manipulations such as presenting list words visually (e.g., Gallo et al. 2001; Kellogg 2001) or presenting pictures (e.g., Israel & Schacter, 1997; Schacter et al. 2001), changing retention interval (Toglia et al. 1999), saying the list words aloud (Dodson & Schacter, 2002), and slowing presentation rates (Gallo & Roediger 2002; McCabe & Smith 2002) in order to eliminate or reduce false memory effect derived from the DRM. One other strategy that can be used to reduce false memories is explicit warnings (giving information and directing participants to monitoring processes). Additionally, there are a few evidences regarding the effect of warning on false memories derived by eyewitness and therapeutic strategies. Some studies demonstrated that explicit warning either reduced false memory rates (e.g., Meade & Roediger 2002) or did not have an effect on false memories (e.g., Green et al. 1998). Moreover, studies using the DRM paradigms to ascertain the effect of warning on false memories also indicated that warning did not eliminate but reduced false recognitions (Gallo et al. 1997; Jou & Foreman 2007; McDermott & Roediger 1998). These results suggest that although false memories elicited by the DRM paradigm are resistant to change, participants might still have somehow eliminated false memories. Yet, explicit warnings are sometimes inefficient in reducing or avoiding false memories.

Up to present, a few studies have investigated several different variables which can interact with the effectiveness of warnings, such as practice (Watson et al. 2004), feedback and incentives (Jou & Foreman 2007), age (McCabe & Smith 2002), and identifiability of items (Neuschatz et al. 2003). Additionally, the timing of warnings may be one important factor which counteract the effect of warnings on false memories. In other words, false and true memories may be differentiated by the time in which of the information processing stages given. Prior research pointed out that warning before encoding (before DRM lists were presented) attenuated false recognition effect (Gallo et al. 1997; McDermott & Roediger 1998). However, warning given before retrieval (after lists were presented but before recognition test were given) was found to have no (Neuschatz et al. 2003) or little effect (Anastasi et al. 2000; Gallo et al. 2001; McCabe & Smith 2002) on false memories. The inconsistency in these findings point to the need for elucidating the role of warning in false memories, especially through interaction with different mechanisms (e.g., stress).

Another possible factor which is likely to exert influence on the effect of warning on false memories, is one's emotional state. In one study, Yang et al. (2014) showed that positive affect increased the effect of warning on false memories derived by DRM paradigm. Similarly, stress may also play a role in the effect of warning on false memory. To the best of our knowledge, no single study has examined

the joint effects of stress and warning on the false memories; however, the effect of stress on human memory has been prominently investigated. For the last decades, it has been documented that stress has complex effects on human memory, with inconsistent findings. While some research indicated that stress impairs human memory (e.g., Lupien et al. 1997; Newcomer et al. 1994, 1999), other research suggested that stress can strengthen memory or has no effect on memory (Smeets et al. 2006a, 2006b). Within this context, it is possible that stress can also be examined as a factor related to memory inaccuracies. Specifically, the effect of increased stress on eyewitness memory has received great attention (for a review, see Deffenbacher et al. 2004) as the nature of crime situations produces a stress response. For instance, Valentine and Mesout (2009) suggested that after a stressful situation, participants with high state anxiety reported more errors when describing the target person, recalling details of the event, and making identifications from a lineup. False memories are also a matter of debate on the reconstruction of trauma-related memories in therapy and techniques used. One major issue is that memory recovery techniques employed in therapy would be considered as a risk factor for false memories (Lindsay & Read 1994). According to Roberts (2002), stress increases vulnerability to false memory for people who are more prone to experience vivid imagery. Furthermore, many studies revealed that trauma-related stress had also an effect on false memories. For instance, people with post-traumatic stress disorder (PTSD) were found to be more prone to memory errors in laboratory experiments (Bremner et al. 2000; Zoelner et al. 2000).

Even though stress emerged as an important factor associated with false memories, only a limited number of DRM studies have investigated the effect of stress on false and true memories. In their first study conducted with the DRM paradigm, Payne et al. (2002) showed that psychosocial stress induced at laboratory settings increased false recognition rates. However, subsequent studies yielded contradictory findings in the role of stress on both false and true memories. For instance, although several studies found that stress did not have an effect on false memories (Beato et al. 2013; Smeets et al. 2006a, 2008), others indicated that stress reduced the false memory rates (Diekelmann et al. 2011; Zoladz et al. 2014). These studies also provided inconsistent effects of stress on true memories of DRM lists (Smeets et al. 2006a, 2008; Zoladz et al. 2014). Thus, to date, there has been little agreement on the effect of stress on false memories.

In sum, while some research has been carried out on false memories and underlying factors, the effect of stress and warning on false memories is not well understood, particularly within the framework of the DRM paradigms. In addition, although previous research put some evidence that

pre-learning stress and pre-learning warning have decreasing effects on false memories, there has been no study examining the joint effects of stress and warning. Thus, more research is needed to elucidate the potential effects of both variables on false memories. From this point, the purpose of the current study is to investigate both the main and interaction effects of psychosocial stress and warning given at different stages of information processing (i.e., before encoding and before retrieval) on false memories by using the DRM paradigm. After reviewing from the existing body of research, we hypothesized that false recognition rates of participants in stress induction group would be lower than participants in the control (no-stress) group. We also hypothesized that participants given a warning before the DRM lists (before the encoding phase) would have lower levels of false recognition rates than participants who are both unwarned and given warning before the recognition test (before the retrieval phase). Lastly, it was further hypothesized that stress-induced participants who are also given a warning before the DRM lists would have the lowest level of false recognition.

Method

Participants

The sample of the study included a total of 126¹ (87 females and 39 males) undergraduate students between the ages of 17 and 30 years ($M=21$, $SD=2.50$). All participants were freshmen recruited from several departments of Ankara University in Turkey. The exclusion criteria for participants were as follows: having a psychiatric diagnosis and using psychiatric medication or drugs. No participants were excluded based on these criteria. The study was approved by the Ethics Committee of Ankara University. Voluntary participants also signed written informed consent.

Materials

Trier social stress test—(TSST) and control task

The TSST is a psychosocial stress test developed by Kirschbaum et al. (1993). It is one of the widely used tests to induce moderate stress, with the evidence that it is a valid

and reliable measure to induce stress both in children, young adults, and elderly adults (Kudielka et al. 2004).

The TSST has three periods, namely a 5-min preparation task, 5-min free speech task, and a 5-min mental arithmetic task. In the preparation period, participants were told that they were required to make a 5-min free speech about themselves for a mock job interview that would be performed in front of two examiners trained to assess their non-verbal behavior. Then, they were given five minutes to prepare for speech and paper and pencil to take notes. After the preparation period, notes were taken from participants. In the free speech period, they were asked to talk continually. Participants were also told that their performance would be evaluated by the investigators. After the free speech task, participants were taken into a 5-min mental arithmetic task in which they were asked to continuously subtract 13 from 1022 as fast as possible and told that they had to return to 1022 if they had a failure in subtraction.

The spielberger state-trait anxiety inventory (STAI)

The STAI was developed by Spielberger et al. (1969) and was adapted into Turkish by Öner and LeCompte (1985). It includes 40 items and has two separate subscales, one of which measures state anxiety and the other trait anxiety. Each item is rated on a 4-point Likert-type scale ranging from 1 (not at all) to 4 (extremely). Total scores of subscales change between 20 and 80 and higher scores indicate higher anxiety levels. The scale demonstrated high internal consistency with a Cronbach alpha of 0.88 (Grös et al. 2007). The state subscale of the STAI was used as a subjective measure to verify the TSST as an effective stress induction method. In the current study, Cronbach's alpha was 0.92 for state anxiety subscale.

DRM word lists

The participants were presented ten-word lists that were used in the original DRM study (Roediger & McDermott 1995). Although original DRM lists consist of 15 words, in the Turkish adaptation study (Mısırlısoy 2004), each list consists of 12 words because of appropriate translation, with a critical lure that is associated with the words in the list. Each list is shown in a slide show and each word is shown for approximately 2 s by the experimenter and then a white, blank slide is shown after each word for 2 s. After the word lists are finished, participants are asked to recognize as many words as they saw on the lists given. The recognition list is composed of studied words, critical lures, and unrelated distractors (words).

¹ A power analysis using G*power 3 (Faul et al. 2007) indicated that a sample size of 158 was sufficient to conduct univariate ANOVA with six groups with a medium effect size, 80% power, and .05 alpha error probability. However, due to the COVID-19 pandemic, we were able to reach 126 participants in total, which is adequate to implement the analyses.

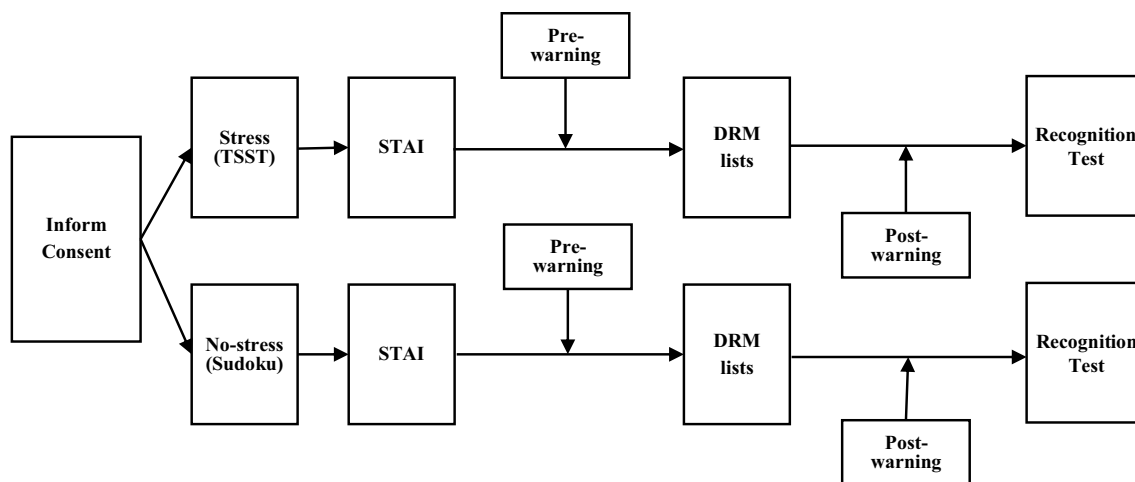


Fig. 1 Schematic overview of the experimental procedure

Design and procedure

A 2 (Stress: stress vs. no-stress control) X 3 (Warning: pre-warning vs. post-warning vs. no-warning) factorial design was used, with both factors manipulated between participants. Thus, participants were randomly assigned to one of six groups. The main dependent variables were the rate of studied words (words presented in the DRM lists), critical lures (critical items of presented DRM lists), and unrelated distractors.

Participants were tested in individual sessions. After arrival in the laboratory, they were informed about the memory tests and were given an informed consent form. All of the participants filled the demographic information form at the beginning of the session. Next, half of the participants were exposed to the TSST (Kirschbaum et al. 1993), while the other half were assigned to a control group that included a filler task (in this case a Sudoku puzzle). Both the TSST and filler tasks took the same duration for all participants. Then, participants were asked to complete the STAI.

Immediately, after the TSST, participants in pre-warning groups (stress/pre-warning, and no-stress/pre-warning) were given detailed information about false memories and warned to be careful about these false memories. They were also instructed to watch 10 DRM lists and to try to memorize each word as they would be subjected to a recognition test. Then, DRM lists were administered. After DRM lists ended, they undertook the recognition task. Participants in the post-warning groups (stress/post-warning, and no-stress/post-warning) were first instructed to watch 10 DRM lists and to try to memorize each word as they would be subjected to a recognition test immediately after the TSST. Then, DRM lists

were administered. Later, they were given detailed information about false memories and warned to be careful about these false memories related to the DRM lists they just watched during the recognition task. Then, they undertook the recognition task. Participants in the no-warning groups (stress/no-warning, and no-stress/no-warning) were given no information and no warning about false memories at any time during the session. They were just instructed to watch 10 DRM lists and to try to memorize each word as they would be subjected to a recognition test immediately after the TSST. Then, DRM lists were administered. Finally, they undertook the recognition task. At the end of the study, participants were given a debriefing form in order to explain the real aim of the TSST task and the study. Figure 1 depicts the experimental design with each measurement used.

Statistical analysis

An independent samples t test was utilized to compare the means of state anxiety scores of stress and control groups in order to reveal the effect of the TSST on stress induction. 2 (Stress: stress vs. no-stress control) X 3 (Warning: pre-warning vs. post-warning vs. no-warning) ANOVAs were carried out in order to test the true and false recognition in experimental groups. Subsequently, Tukey post hoc analysis was performed to compare warning groups. For true and false recognition, mean scores were presented with their standard deviations (SD). All analyses were conducted in SPSS 20 (Statistical Package for the Social Sciences) with a significance level of $\alpha=0.05$. In the ANOVAs, partial eta squared (η_p^2) were used to indicate effect size.

Table 1 Comparison of the STAI scores of stress induction and control group

Groups	<i>N</i>	<i>M</i>	<i>SD</i>	<i>df</i>	<i>t</i>	<i>p</i>
Stress induction	63	43.33	10.44	124	5.81	.000
Control	63	33.84	7.79			

Table 2 Comparison of list types in terms of stress and warning and descriptive statistics

	Studied Words		Critical Lures	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
<i>Stress</i>				
Stress	.63	.15	.58	.22
No-stress	.75	.15	.62	.20
<i>Warning</i>				
Pre-warning	.68	.16	.59	.18
Post-warning	.65	.15	.53	.25
No-warning	.73	.15	.67	.20

Results

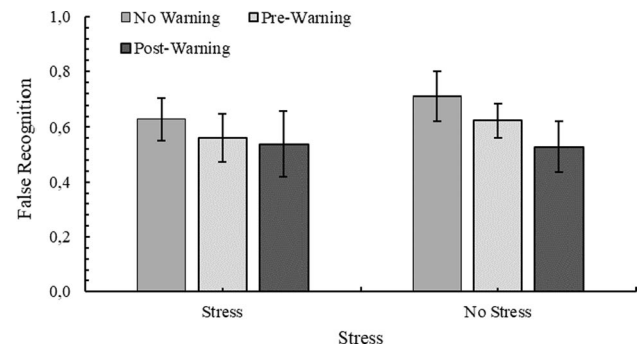
Manipulation check

Results of independent samples *t* test indicated a significant difference between the two groups [$t(124) = 5.81$, $p < 0.001$], with the higher level of state anxiety among participants in the stress induction group ($M = 43.33$, $SD = 10.44$) compared to those in the control group ($M = 33.84$, $SD = 7.69$) (see Table 1). In sum, TSST can be regarded as an effective stress induction protocol by the subjective ratings of the participants.

Main analysis

Descriptive statistics for the DRM recognition task are shown in Table 2.

A 2 (stress condition: stress, no-stress) X 3 (warning condition: pre-warning, post-warning, and no-warning) factorial design ANOVA was conducted in order to test whether false recognition was differentiated by stress and warning. Results indicated that the main effect of warning was found to be statistically significant ($F_{(2-120)} = 4.43$, $p = 0.014$, $\eta_p^2 = 0.07$). For further post hoc analysis, Tukey's HSD test ($p < 0.05$) was carried out. Results indicated that recognition rates of participants in the post-warning condition ($M = 0.53$, $SD = 0.25$) was significantly lower than the no-warning condition ($M = 0.67$, $SD = 0.20$) (see Table 2; Fig. 2). However, recognition rates of participants in the pre-warning condition ($M = 0.59$, $SD = 0.18$) were not found to be significantly different from other groups.

**Fig. 2** Effect of stress and warning on false recognition (error bars represent 95% Confidence Interval [CI])

Neither the main effect of stress nor interaction effect for stress and warning on false recognition was found to be significant (see Table 3).

A 2 (stress condition: stress, no-stress) X 3 (warning condition: pre-warning, post-warning, and no-warning) factorial design ANOVA was conducted in order to test whether true recognition was differentiated by stress and warning. Results indicated that the main effect of stress was found to be statistically significant ($F_{(1-120)} = 20.02$, $p = 0.000$, $\eta_p^2 = 0.14$). Recognition rates of participants in the stress condition ($M = 0.63$, $SD = 0.15$) was found to be significantly lower than that of participants in the control group ($M = 0.75$, $SD = 0.15$) (see Table 2; Fig. 3). Moreover, the main effect of warning was statistically significant ($F_{(2-120)} = 3.56$, $p = 0.031$, $\eta_p^2 = 0.06$). For further post hoc analysis, Tukey's HSD test ($p < 0.05$) was implemented. Results indicated that recognition rates of participants in the post-warning condition ($M = 0.65$, $SD = 0.15$) was significantly lower than the no-warning condition ($M = 0.73$, $SD = 0.15$) (see Table 2; Fig. 3). However, recognition rates of participants in the pre-warning condition ($M = 0.68$, $SD = 0.16$) were not significantly different from other groups. The interaction effect between stress and warning on true recognition was also not statistically significant (see Table 3).

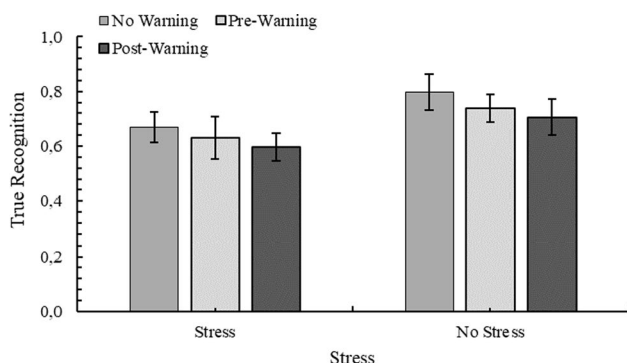
Discussion

The purpose of this study was to investigate the effects of both stress and warning on memory errors. To summarize, this study has three main findings. First, stress was found to be effective on only true recognitions but not on false

Table 3 Effect of stress and warning on studied words, critical lures, and unrelated distractors

	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	η_p^2	<i>p</i>
<i>False Recognition</i>						
Stress	.06	1	.06	1.42	.01	.236
Warning	.39	2	.19	4.43	.07	.014
Stress X Warning	.05	2	.02	.55	.01	.581
<i>True Recognition</i>						
Stress	.42	1	.42	20.02	.14	.000
Warning	.15	2	.07	3.56	.06	.031
Stress X Warning	.00	2	.00	.07	.00	.931

SS = sum of squares; *df* = degrees of freedom; *MS* = mean square; η_p^2 = partial eta-squared

**Fig. 3** Effect of stress and warning on true recognition (error bars represent 95% CI)

recognitions. Second, our findings suggested that in the post-warning condition both false and true recognition rates were significantly lower compared to no-warning condition. Third, the interaction effect of stress and warning on both true and false recognitions were found to be insignificant.

Our findings indicated that stress-induced participants' recognition rates for studied words were found to be significantly lower than the control group. However, false recognition rates of both groups did not differ from each other. Therefore, participants in the stress groups were not likely to commit more false recognition but less true recognition than the participants in the control groups. These findings are consistent with the existing literature indicating that stress has no effect on false memories (Beato et al. 2013; Smeets et al. 2006a), but could not replicate either the study of Zolads et al. (2014) showing that stress decreased the false memories or the study of Payne et al. (2002) showing that stress increased the false memories. In addition, although Smeets et al. (2006a) suggested that acute stress diminished the true recall of DRM lists, this is the first study indicating that true recognitions were diminished by the effect of stress.

Previous studies indicate that there is an inconsistency in the stress and false memory literature. It should be noted that the methodological differences among studies could play a role in such variability of the findings. For instance,

studies differ from each other in that they investigated either false recall or false recognition rates. Yet, this study used a methodology similar to both Payne et al. (2002) and Beato et al. (2002) but revealed different findings in terms of both false and true recognition. One could claim that stress was not inducted effectively, thereby leading to the indifference between stress and control groups. However, we used the same stress induction method (TSST) and our findings showed that STAI-S scores were significantly higher in stress groups than no-stress groups.

A possible explanation might be the stress induction protocol used in this study. Psychosocial stress is one of the widely used methods to investigate the DRM paradigm and false memories. Although as a psychosocial stress induction protocol, the TSST is a strictly defined laboratory method to induce stress, its administration length might affect the physiological processes, which play a role in learning, possibly leading to contradictory findings in a variety of studies in terms of the effect of psychosocial stress on true and false memories. For instance, it was assessed that more brief stressors such as cold pressor might have an enhancing effect on especially hippocampus by priming (Zoladz et al. 2014).

Another possible explanation could be that, rather than stress by itself, a combination of stress and stress-induced cortisol levels might play a role in the memory performances. More specifically, increases and decreases in cortisol levels in different memory stages could be the determinant of differences among the findings of stress and false memory literature. For instance, Buchanan and Lovallo (2001) found that stress induced at perception and encoding phases was associated with an increase in cortisol level as well as an increase in memory performance. Adversely, the interaction between stress induced at retrieval phase and cortisol level was found to lead to an impairment in memory performance (Buchanan et al. 2006; Kuhlman et al. 2005). Another study suggested that stress enhanced the recall of emotional stimuli when a cortisol effect did not occur (Buchanan & Tranel 2008). Taken together, it can be assumed that the combination of findings from our study and previous studies provides some support for the conceptual

premise that source and kind of stress (as in stress protocols), memory phase that stress is induced and physiological changes after stress contribute to both true and false memory performance. However, importantly, the interaction between all of these variables could specify the direction of their effect on memory performance.

In addition to stress, this study indicated that the warnings had differential effects on false memories. The results are somehow both consistent and inconsistent with the existing body of research. It was previously documented that although warning participants about the effect of the DRM paradigm did not eliminate false memories, it resulted in a significant reduction (e.g., Gallo et al. 1997). Moreover, previous studies indicated that although warning given before the encoding phase decreased false memories (Gallo et al. 1997; McDermott & Roediger 1998), warning given at the retrieval phase did not affect false memories (Neuschatz et al. 2003). In contrast to these findings, the results of the present study revealed that participants given warning before the encoding phase were not found to be different in the levels of false recognitions than those who did not receive any warnings whereas participants who received a warning before the retrieval phase demonstrated lower levels of false recognition.

False memory theories may explain and provide a basis for interpreting our findings. At first, according to the Source Monitoring Theory (SMT), the association between incorrect source misattributions at the retrieval phase and properties of experiences at the encoding phase might lead to errors in source monitoring (Cowley 2006; Mammarella & Fairfield 2008; Mitchell & Johnson 2000). Accordingly, warning at the retrieval phase might inhibit the attribution of information to wrong sources. For instance, Cowley (2006) found that a person receiving wrong information from another person after an event might appraise this event falsely. This suggests that external information received after an event can be stored as if the individual's own mental experience and false sources are used at the retrieval phase. Warning given at the retrieval phase might have an exactly opposite effect and increase source monitoring performance and further make individuals focus on the right information in the memory. In other words, participants might have separated the incoming information from false sources. On the other hand, participants given a warning before the DRM word lists were presented could not have focused on the source of the right information. The warning in the coding phase might have caused the incorrect coding of incoming information. That is, instead of focusing on the words in the lists, participants might have focused on finding possible words that may be associated with the word lists, possibly leading to incorrect coding of the corresponding source of information.

Moreover, the Activation / Monitoring Theory (AMT) can also contribute to elucidate the findings of the present

study. According to the AMT, implicit associative processes play a role during the encoding of word lists (Roediger & McDermott 1995). If these associative processes are attributed to external sources, false memories can emerge. In other words, it is expected that participants are likely to report that they have seen the critical lures due to their associations and source misattributions. Accordingly, warning prior to the encoding phase may have triggered implicit associative processes when the lists are being displayed, possibly resulting in source misattributions. In one study (Paterson et al. 2012), it was suggested that when the time between misinformation and warning phases increased, the warning did not affect the false memories, which indicates that time might cause source monitoring errors.

Lastly, although the effect of warning on true recognition was not in the scope of this study, exploratory analysis yielded that the warnings also had differential effects on true memories. This finding suggests that in the post-warning condition, true recognition rates were significantly lower than in the no-warning condition. As in prior research with false recognitions, there are contradictory results in relation to the effect of warning on true recognitions. Our results are in agreement with Gallo et al. (1997) findings which also showed that participants who were forewarned about false memories recalled less studied words than participants who did not get any warning. On the other hand, in another study, Peters et al. (2008) indicated that warning had no significant effect on true recognitions. Thus, future studies focusing on the specifics of how and through which mechanisms warning may affect true recognitions are needed.

To summarize, although our results do not indicate any association between stress and false memories, an increase in the level of stress was associated with a decrease in true recognition performance. As such, it is still important for both researchers and experts to be cautious about the reliability of memory in stressful situations. This study also provides important implications about the effect of warnings on false memories. It was suggested that the timing of the warning might be an important indicator of the effect of warning on false memories. Lastly, as mentioned before, although previous research put some evidence that stress and warning affected false memories, this was the first study that investigated the combined effects of stress and warning. The findings did not put evidence that stress and warning interacted with each other. Thus, the main contribution of this study is that the combined effect of stress and warning might be insufficient to eliminate the false memories. Further comprehensive research, (e.g., replication studies) should be undertaken to investigate the associations between lab-induced stress, warnings, and memory performance and to understand which mechanisms lead to inconsistencies in the false memory.

Despite the present study has important implications, the results of the present study should be interpreted with its limitations. First, the number of participants was relatively low, which may affect the statistical power of the research. This study is needed to be replicated with a large number of participants to get clearer results. Second, since stress leads to novel and fluctuating responses in organisms, instruments aiming to measure these fluctuating responses such as skin conductance (Harrison et al. 2006) and serum cortisol levels (Kirschbaum et al. 1993) in a timely fashion manner can be used to receive more reliable measurements of stress experienced by the participants. Third, in the literature, there are a few studies indicating that it might be important to induce stress at different memory processing stages (Buchanan & Lovallo 2001; Buchanan et al. 2006; Kuhlman et al. 2005). However, in the present study, such a comparison was not conducted. Lastly, the findings of this study add only our understanding of short-term effects of the stress and warning on memory performance, rather than the effects on long-term memory.

Author Contributions Some part of the data used in this study is based on the master's thesis of the first author. All authors contributed to the study conception and design. All authors read and approved the final version of the manuscript.

Availability of data and material The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Conflicts of interest The authors have no conflicts of interest to declare that are relevant to the content of this article.

Ethics approval Approval was obtained from the ethics committee of Ankara University.

Consent to participate Informed consent was obtained from all individual participants included in the study.

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