Journal of Psychological and
Educational Research
JPER - 2022, 30 (2), November, 7-19
e-ISSN: 2821-4099

THE EFFECTS OF PHYSIOLOGICAL STRESS ON LEARNING INSTRUCTIONAL MATERIALS

Aleyna Su Tuncol
Çankaya University, Turkey

Betul Beyza Cengil
Social Sciences University of Ankara, Turkey

Oyku Aydın
Çankaya University, Turkey

Hande Kaynak
Çankaya University, Turkey

Erol Ozcelik [*]
Çankaya University, Turkey

Abstract
Psychophysiological studies have shown that stress can both enhance and impair learning. However, there is not enough research on the effects of stress on learning ecologically valid materials. Considering this need, the goal of the current study is to examine the effects of physiological stress on learning instructional materials. Thirty-eight healthy participants held their hands in either ice-cold water (cold pressor stress group) or warm water (control group) for three minutes after studying the instructional material. Learning was assessed by recall and recognition tests given on the following day. The results showed that physiological stress impaired recall but did not affect recognition, suggesting that extreme stress levels had a detrimental effect on learning tests that rely on self-initiated cues.

Keywords: post-learning stress; learning; cold pressor test

Introduction

Stress activates the sympathetic nervous system by releasing cortisol hormones to prepare the organism for fight or flight responses. The release of cortisol also influences human memory and learning through its effect on the hippocampus and amygdala, which are rich in cortisol receptors (Lindau, Almkvist, & Mohammed, 2016). Studies have shown that stress affects the encoding, consolidation, and retrieval processes of human memory (Cahill, Gorski, & Le, 2003; Roozendaal, McEwen, & Chattarji, 2009; Zoladz et al., 2015). However, stress can both enhance and impair memory. For instance,

Correspondence concerning this paper should be addressed to:

[*] Çankaya University, Faculty of Arts and Sciences, Department of Psychology. Ankara, Turkey. Address: Eskişehir Yolu 29. km, Yukarıyurtçu Mahallesi Mimar Sinan Caddesi, No:4, 06790, Etimesgut, Ankara, Turkey. Phone: +90 312 233 1447; Fax: +90 312 286 40 78 E-mail: *ozcelik@cankaya.edu.tr*
ORCID: 0000-0003-0370-8517

permanent impairments in long-term memory may be caused by chronic stress (McCullough & Yonelinas, 2013; McEwen & Sapolsky, 1995). The positive or negative effect of stress on memory consolidation depends on the time of inducement of stress (Zoladz et al., 2015). Studies in which stress was induced after a learning session (post-learning stress) revealed that stress enhanced the consolidation process of memory (Buchanan & Tranel, 2008; Joëls, Pu, Wiegert, Oitzl, & Krugers, 2006; McCullough & Yonelinas, 2013; McGaugh, 2000; Roozendaal, 2000; Schwabe, Joëls, Roozendaal, Wolf, & Oitzl, 2012; Zoladz et al., 2015). Although Trammell and Clore (2014) applied the same procedure, they found that post-learning cold pressor stress, which exposed one to three minutes, impaired the long-term memory of pictures and words. On the other hand, acute stress induced by ice water (*i.e*., cold-pressor test) over the course of retrieval or just before retrieval may damage the retrieval process (De Quervain, Roozendaal, & McGaugh, 1998; Kuhlmann, Piel, & Wolf, 2005; McCullough, Ritchey, Ranganath, & Yonelinas, 2015; Schwabe, Wolf, & Oitzl, 2010; Smeets, Otgaar, Candel, & Wolf, 2008).

In the relevant literature, when examining the effects of stress on memory, cortisol, which is released as a result of stress, is thought to be the main effector (De Kloet, Oitzl, & Joels, 1999; Het, Ramlow, & Wolf, 2005; Schwabe, Bohringer, Chatterjee, & Schachinger, 2008). The release of cortisol around the time of learning enhances learning processes. Thus, enhancement in memory is expected when stress is experienced just before learning (Joëls et al., 2006). For instance, Nater et al. (2007) revealed that high cortisol responses indicated better recall performance than low cortisol responses to stress. Despite these results pointing out that stress hormones facilitate learning, if the amount of the hormones (*e.g*., cortisol) is excessive, then it results in a diminishment of learning (Joëls et al., 2006). Stress hormones levels induce an inverted U-shaped effect on memory and learning (Baldi & Bucherelli, 2005; Conrad, 2005; Joëls, 2006; Sandi & Pinelo-Nava, 2007). More specifically, when levels of stress hormones are too high or too low, they impair memory, whereas midrange levels enhance memory (Akirav et al., 2004; Andreano & Cahill, 2006; Lupien et al., 2002). Even though the effects of stress on memory and learning are relatively well understood, there is not enough research on the effects of stress on learning in an applied educational material. In light of this necessity, the goal of the current study is to examine the effects of stress on learning instructional materials in a more ecologically valid material for education.

Many studies have confirmed that emotionally loaded and arousing events (*e.g*., stressful events) are generally remembered better than non-emotional ones due to consolidation processes (LaBar & Cabeza, 2006; McGaugh, 2000, 2004; Nielson & Lorber, 2009). Consolidation of information is generally associated with the hippocampus and the caudate nucleus (McGaugh, 2002). In addition, processes of hippocampal memory consolidation are affected by the amygdala (McGaugh, 2002). Specifically, the influence of emotion on memory consists of stress hormones release and activation of the basolateral amygdala (LaLumiere, McGaugh, & McIntyre, 2017). The basolateral amygdala and stress hormones collaborate in modulating memory consolidation (LaLumiere et al., 2017).

Behavioral studies have suggested that stress systems are activated during the encoding of only emotional information (Cahill et al., 2003; Liu, Graham, & Zorawski, 2008; Smeets et al., 2008). On the other hand, some studies have found that post-encoding stress enhances the recall of both emotional and neutral materials (*e.g.*, Nielson & Lorber, 2009). Besides, other studies indicated better recall performance for neutral materials but not for emotional ones (*e.g.*, Preuß & Wolf, 2009). However, literature on the effects of stress on learning instructional materials is missing.

Cold pressor stress (CPS) is an effective instrument for examining the effect of stress on memory consolidation and modulation (Cahill et al., 2003). Cold pressor is mainly used in a procedure where participants are exposed to cold water. Therefore, CPS induces stress due to an increment in skin conductance (Buchanan, Tranel, & Adolphs, 2006) and discomfort (Cahill et al., 2003). CPS also influences heart rate and blood pressure, which are involuntarily regulated by the autonomic nervous system (*e.g.*, Larra et al., 2014). Stress stimulates the organism to be ready for the related event by increasing heart rate and blood flow. Previous studies have confirmed that CPS is a reliable tool for inducing stress (Cahill et al., 2003; Schwabe et al., 2008). With the idea of expanding the previous limited works, we focused on exploring the effects of CPS on learning.

Objectives

Given the previous research, this study had the goal to investigate how stress induced by CPS affects learning. We hypothesized that midrange stress would enhance memory consolidation, whereas high stress would impair memory consolidation. The CPS task was used to create high stress in the current work. Therefore, we expected that participants in the CPS condition would perform worse on recall and recognition of instructional passages than those in the control condition.

Method

Participants

A total of 38 undergraduate students were voluntarily recruited by a convenience sampling method. One participant was excluded from the data set because the participant reported that s/he had a psychiatric disorder and took medication. Therefore, analyses were carried out with 27 females and 10 males whose ages ranged from 21 to 26 (M=22,51; SD=1,12), with a total of 37 participants. Those participants reported no psychiatric/psychological disorders or medication history. Participants were randomly assigned to the experimental (CPS) condition (n=18, 13 female, 5 male) or the control condition (n=19, 15 female, 4 male). All 37 subjects participated in a follow-up memory test session on the following day. At the beginning of the first session, informed consent was obtained from the participants. However, they were partially briefed about the procedure. They were told that they would be tested on the learning material the following day. They were not, however, informed about the hand immersion task. After the second session, the participants were truly informed about the nature of the study.

Materials

Demographic Information Form. After relevant literature was searched, the experimenters created a demographic information form by considering the variables that may affect learning performance and memory consolidation. The form included questions about chronological age, dominant hand, grade, cumulative grade point average (cumGPA), psychiatric/psychological disorder and medication history, smoking status, number of cigarettes smoked per day, irregularity of menstrual cycle for females, gender, and substance use.

Depression Anxiety Stress Scale-21 (DASS-21). DASS-21 was developed by Lovibond and Lovibond (1995) to assess individuals' depression, anxiety, and stress levels. The scale consists of 21 items on a four-point Likert scale ranging from 0 (never) to 3 (always), having sub-scales of depression (7 items), anxiety (7 items), and stress (7 items). The Turkish adaptation, validity, and reliability study of DASS-21 was conducted by Sarıçam (2018). In this study, the Cronbach Alpha internal consistency reliability coefficients of the sub-scales were reported as .87 for depression, .85 for anxiety, and .81 for stress. In the original study, test-retest correlation coefficients were found as .68 for depression, .66 for anxiety, and .61 for stress subscales.

Prior Knowledge Test. This test was designed by the experimenters to assess the participants' prior knowledge about the content of the learning material. The test included five questions on a five-point Likert scale about the material (*i.e*., immune system). Participants could get scores between 5 (very little knowledge) to 25 (very much knowledge), and higher scores indicated that participants had greater knowledge about the topic. The reliability of the prior knowledge test was examined by Cronbach's alpha coefficient. The Cronbach's alpha coefficient was .83, indicating that the internal consistency of the prior knowledge test was good.

Instructional Material. In the current study, instructional materials were created by the experimenters. The eight-page material consisted of both visual and verbal information about the immune system. It was given to the participants in printed paper format.

Visual Analog Scales. Three visual analog scales were used to measure levels of stress, pain, and unpleasantness felt immediately after the hand immersion task (Price, McGrath, Rafii, & Buckingham, 1983; Smeets et al., 2008). Participants were asked to mark their subjective feelings scored from 0 ("not at all") to 100 ("extremely") in units of 10.

Recall and Recognition Tests. These tests were designed to test the participants' learning performance. On the second day of the experiment, the recall task was first given and followed by the recognition task. The recall task consisted of six open-ended questions (five points each). On the other hand, the recognition task included 26 multiple choices questions (one point for each). A standard answer key was designed for both open-ended and multiple-choice questions. The answers of each participant were rated for the open-ended questions. In order to test the reliability of the recall test, another rater, who was blind to conditions, rated ten tests that were selected randomly. The interrater reliability of the recall test was examined by the interclass correlation coefficient (ICC) based on absolute agreement and a 2-way mixed-effects model. The ICC was found to be .98 (CI .93 to .99), indicating excellent reliability of the recall test. The internal consistency reliability of the recognition test was assessed using the Kuder-Richardson 20 formula, which yielded a coefficient of .67. This result shows that the recognition test had acceptable internal consistency.

Apparatus

Heart rate and blood pressure were measured using a sphygmomanometer (Omron, M2, Tokyo, Japan) positioned in the appropriate place on the upper arm according to the participants' dominant hand because the other hand was in the water. Results were recorded by the experimenter.

Hand Immersion Task

In the hand immersion task, participants put their non-dominant hands up to their wrists to the water. The water temperature was at room temperature (19-26°C) in the control condition, whereas the temperature was between -2 to 5 degrees centigrade in the CPS condition to make the participants stressed. Both groups had to hold their hands for three minutes without taking their hands off the water. However, if the participants were unable to complete the task, they were not forced. Participants had the option to draw back their hands when they could not bear the pain.

Procedure

Before starting the study, research ethics committee approval was received by the Ethical Committee of Çankaya University. Each participant was tested in a controlled laboratory environment in two sessions on two consecutive days. Participants were requested not to consume nicotine and caffeine before the first session of the experiment to eliminate their potential effects on stress. In the first session of the experiment, participants were required to fill out the informed consent, demographic information form, DASS-21, and prior knowledge test. Afterward, the instructional materials were given to the participants with no time limitation. Experimenters recorded the study time of the participants by a stopwatch. Before the material was given, participants were informed that they would be asked open-ended and multiple-choice questions about this material the following day. When the participants reported that they had finished studying the material, their blood pressure and heart rate were measured with the sphygmomanometer. Participants were randomly assigned to one of the two conditions. Just after, participants' non-dominant hands (up to the wrist) were put on water according to the assigned condition. They were instructed to keep their hands in the water for three minutes straight, although it was also indicated that they were free to draw back their hands whenever they wanted. The experimenters also told the participants that they were recorded with a camera during these three minutes in order to elevate cortisol responses (Schwabe et al., 2008), but the camera was fake. Just before they drew back their hands, their blood pressure and heart rate were measured with the sphygmomanometer. After the participants pulled back their hands from the water, they dried their hands with a towel provided by the experimenters. As a last step of the first session, questions related to how they felt about putting their hands in the water were asked to the participants with the subjective ratings of emotional variables.

Participants filled out the recall and then the recognition tests in the second session. Experimenters recorded the amount of time that the participants completed each test. At the end of the experiment, participants were informed about the true nature of the experiment. The deceptions about the camera and hand immersion task were explained in detail.

Statistical Analyses

A sample size estimation procedure was conducted using G*Power software package (Version 3.1.9.4, Kiel University). The results suggested that the required sample size was 36 for a Mann-Whitney U test (two groups) with effect size =1.18 as reported by Hupbach and Fieman (2012), α=0.05, power=0.95. Statistical analyses were performed by the IBM SPSS Statistics 23 software with a statistical significance criterion of $p<.05$. A non-parametric method, the Mann-Whitney U test was employed to examine whether there existed statistically significant differences in the dependent variables (*e.g.*, recall performance) between the control and CPS groups, since all the dependent variables did not meet the normality assumption.

Results

Only seven participants draw their hand back before three minutes with a range from 58 to 167 seconds (M=101.43). The results of the Mann-Whitney U test suggested that there existed no significant difference between the groups in prior knowledge (U=143.0, p=.27, η_p^2=.02), study time (U=163.0, p=.61, η_p^2=.002), time spent on recall test (U=156.0, p=.47, η_p^2=.006), and time spent on recognition test (U=154.5, p=.45, η_p^2=.007). In addition, depression (U=157.0, p=.49, ηp2=.005), anxiety (U=161.0, p=.57, η_p^2=.002), and stress (U=175.0, p=.87, η_p^2=0) before the manipulation were comparable between the groups. These results suggested that the groups were comparable for prior knowledge of the subject matter, study time, time spent on recall and recognition tests, depression, anxiety, and stress before the manipulation (*see* Table 1).

Table 1. Mean and standard deviation for the control and CPS groups for prior knowledge, cumulative GPA, study time, time spent on the recall test, time spent on the recognition test, depression, anxiety, and stress

Variable	Control Group		CPS Group	
	M	SD	M	SD
Prior knowledge	10.21	4.53	8.95	5.50
Cumulative GPA	3.04	0.69	3.25	0.49
Study time (in seconds)	776.47	353.03	796.68	300.03
Time spent on recall test (in seconds)	296.89	174.06	320.74	149.50
Time spent on recognition test (in seconds)	331.26	53.44	323.89	87.12
Depression before the manipulation	4.89	3.38	5.84	4.25
Anxiety before the manipulation	4.42	3.78	3.47	2.99
Stress before the manipulation	7.21	3.94	7.53	4.89

The results of the Mann-Whitney U test showed that there was no significant difference between the CPS group and control group in autonomic arousal variables, which are systolic blood pressure (U=159.5, p=.54, η_p^2=.003), diastolic blood pressure (U=146.5, p=.32, η_p^2=.02), and heart rate (U=170.0, p=.76, η_p^2=0) before the manipulation. These results provide evidence that the CPS and control groups showed similar autonomic arousal levels before the manipulation (*see* Table 2). Moreover, the Wilcoxon signed-rank test was administered to compare autonomic arousal variables before and after the intervention of CPS. The results reveal that there was a significant increase in systolic blood pressure (Z=-3.83, p<.001, r=.63) and diastolic blood pressure (Z=-3.10, p=.002, r=.51) for the CPS group (*see* Table 2), but not for the control group (for systolic blood pressure Z=-0.67, p=.51, r=.11; for diastolic blood pressure Z=-1.73, p=.47, r=.28). There was no significant difference in heart rate measures before and after the intervention for both the CPS group (Z=-0.08, p=.94, r=.01) and control group (Z=-1.17, p=.24, r=.18). Taken together, these results suggest that autonomic arousal with elevated blood pressure was observed for the CPS group but not for the control group.

Table 2. Mean and (standard deviation) for control and CPS groups on autonomic arousal variables

Variable	Control Group		CPS Group	
	Before intervention	After intervention	Before intervention	After intervention
Systolic blood pressure	101.89 (11.82)	103.11 (11.30)	104.74 (10.35)	121.05 (13.60)
Diastolic blood pressure	66.32 (8.26)	65.37 (8.38)	69.74 (8.48)	80.05 (13.65)
Heart rate	76.11 (14.26)	77.53 (14.58)	77.21 (8.34)	77.47 (8.11)

Table 3. Mean and standard deviation for the control and CPS groups for subjective stress, pain, unpleasantness, recall, and recognition

Variable	Control Group		CPS Group	
	M	SD	M	SD
Subjective stress	11.05	14.11	43.16	32.50
Pain	3.68	4.96	58.95	30.53
Unpleasantness	17.89	21.23	60.00	32.83
Recall	8.86	5.47	6.91	4.13
Recognition	17.37	4.18	17.89	2.47

Discussion

The main aim of this study was to assess the effect of physiological stress induced by cold pressor on learning. Results revealed that the CPS task increased the systolic and diastolic blood pressure of the participants in the CPS group but not in the control group. This finding indicated that autonomic arousal with elevated blood pressure was found in the CPS group as hypothesized. Besides, the results showed that the subjective stress, pain, and unpleasantness ratings of the CPS group were significantly higher than the ones of the control group. Taken together, all these results suggested that the CPS manipulation was successful. More importantly, the recall performance of the CPS group was found to be worse than the control group, which was in accordance with our hypothesis. In contrast, the recognition performance of the groups did not differ significantly from each other. Therefore, it can be concluded that the stress induced by cold pressor impaired recall performance. McCullough et al. (2015) indicated an inverted-U-shaped relation between CPS stress and recall performance of the participants. This means that moderate levels of stress-related changes due to cold pressor provide highest performance on recall test (McCullough et al., 2015). Considering the results of the current study, it can be interpreted that impairment of the recall performance of the CPS group may be caused by extreme levels of stress, in line with the inverted-U shaped stress and performance relationship. In other words, the CPS exposure may cause an extreme increment in participants' stress levels.

One of the contributions of this study is that both recognition and recall tests were applied to evaluate learning. Recall and recognition tests require different kinds of cognitive processes by their nature. Recall tests rely on self-initiated cues, whereas recognition tests require more familiarity-based processes (Yonelinas, 2002). The majority of the previous studies (*e.g.*, Andreano & Cahill, 2006; Buchanan & Tranel, 2008; Cahill et al., 2003; Trammell & Clore, 2014; Zoladz et al., 2015) applied the recall tests for evaluating the effects of stress on learning. Since the current study is one of the rare studies in which both types of tests (*i.e.*, recall and recognition) with different types of cognitive processes are applied, it is thought that this study will make significant contributions to the field. In the relevant literature, several studies have used word lists (*e.g.*, Trammell & Clore, 2014; Zoladz et al., 2015) and pictures (*e.g.*, Buchanan & Tranel, 2008; Cahill et al., 2003; Felmingham, Tran, Fong, & Bryant, 2012;

Kuhlmann & Wolf, 2006; Larra et al., 2014; McCullough et al., 2015; McCullough & Yonelinas, 2013; Steidl, Mohi-Uddin, & Anderson, 2006) to test learning. However, in our study, an instructional passage was used as the learning material. Instead of using images or word lists, using a real-world learning material enhanced the validity of the study.

Conclusion

An apparent limitation of the method is that we were not able to evaluate the change in the cortisol levels of the participants due to CPS. If physiological assessments such as cortisol levels were applied, the effects of CPS on learning could have been observed more directly. Another limitation in the current study is the small sample size. Due to the current COVID-19 pandemic, a limited number of participants could participate in this face-to-face study. Hence, it is considered that recruiting an insufficient number of participants and outnumbering female participants might affect the results of the study. In the relevant literature, there are contradictory results on learning and sex relation. Specifically, some studies (Felmingham et al., 2012; Zoladz et al., 2014) indicated that stress enhances memory in females, whereas another study suggested that stress enhances consolidation in males (Andreano & Cahill, 2006). From this perspective, recruiting an equal number of participants from each sex might be insightful for better understanding the relationship between stress and learning. Lastly, participants were instructed to keep their hands in the water for three minutes, although some of them were not able to keep their hands for that course of time. Therefore, this could also affect the results.

In sum, the presented results have shown that CPS impaired the recall performance. This finding supports the inverted U-shaped relationship between stress and learning in the literature (*e.g.*, Baldi & Bucherelli, 2005) such that high levels of stress caused by the CPS task hinders learning. One of the contributions of the current to the field is to show the negative effects of stress on learning instructional materials in a more ecologically valid material for education. However, no impairment was observed for recognition performance. The findings obtained for recall performance were seen as inconsistent with the general notion in the relevant literature. The general notion of the literature suggests that induced stress enhances the recall performance of the participants (*e.g.*, Buchanan & Tranel, 2008; Joëls et al., 2006; McCullough & Yonelinas, 2013; McGaugh, 2000; Roozendaal, 2000; Schwabe et al., 2012; Zoladz et al., 2015). Therewithal, it is also proposed that when CPS is induced in the post-learning phase, the task is seen as a distractor preventing the rehearsal of the learning material, which may, consequently, impair learning (Trammell & Clore, 2014).

Some recommendations are given for future studies. First, the potential effects of attention on learning should be considered in a more detailed way. Besides, it will be important for future studies to investigate the physiological reactions (*e.g.*, cortisol level changes). Additionally, limited samples of the present study were only recruited from university students. Yet, studies with various age groups and larger samples should be conducted to better understand the nature of learning processes in stress-induced participants.

Ethics statement

This study was carried out in accordance with the recommendations of the Code of Ethics of Çankaya University. The protocol was approved by the Social Sciences and Humanities Ethics Committee of the Çankaya University. In accordance with the Declaration of Helsinki, all parents gave written informed consent for adolescents' participation in the study.

Conflicts of interest

The authors declare no conflict of interest.

Author contributions

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

Funding

This research received no external funding.

References

Akirav, I., Kozenicky, M., Tal, D., Sandi, C., Venero, C., & Richter-Levin, G. (2004). A facilitative role for corticosterone in the acquisition of a spatial task under moderate stress. *Learning & Memory*, *11*(2), 188-195.

Andreano, J. M., & Cahill, L. (2006). Glucocorticoid release and memory consolidation in men and women. *Psychological Science, 17*(6), 466-470.

Baldi, E., & Bucherelli, C. (2005). The inverted "U-shaped" dose effect relationships in learning and memory: Modulation of arousal and consolidation. *Nonlinearity in Biology, Toxicology, and Medicine*, *3*(1), 9-21.

Buchanan, T. W., & Tranel, D. (2008). Stress and emotional memory retrieval: effects of sex and cortisol response. *Neurobiology of Learning and Memory, 89*(2), 134-141.

Buchanan, T. W., Tranel, D., & Adolphs, R. (2006). Impaired memory retrieval correlates with individual differences in cortisol response but not autonomic response. *Learning & Memory, 13*(3), 382-387.

Cahill, L., Gorski, L., & Le, K. (2003). Enhanced human memory consolidation with post-learning stress: Interaction with the degree of arousal at encoding. *Learning & Memory, 10*(4), 270-274.

Conrad, C. D. (2005). The relationship between acute glucocorticoid levels and hippocampal function depends upon task aversiveness and memory processing stage. *Nonlinearity in Biology, Toxicology, and Medicine, 3*(1), 57-78, 2005.

De Kloet, E. R., Oitzl, M. S., & Joels, M. (1999). Stress and cognition: Are corticosteroids good or bad guys? *Trends in Neurosciences*, *22*(10), 422-426.

De Quervain, D. J., Roozendaal, B., & McGaugh, J. L. (1998). Stress and glucocorticoids impair retrieval of long-term spatial memory. *Nature*, *394*(6695), 787-790.

Felmingham, K. L., Tran, T. P., Fong, W. C., & Bryant, R. A. (2012). Sex differences in emotional memory consolidation: the effect of stress-induced salivary alpha-amylase and cortisol. *Biological Psychology*, *89*(3), 539-544.

Het, S., Ramlow, G., & Wolf, O. T. (2005). A meta-analytic review of the effect of acute cortisol administration on human memory. *Prychoneuroendrocrinology*, *30*(8), 771-784.

Hupbach, A., & Fieman, R. (2012). Moderate stress enhances immediate and delayed retrieval of educationally relevant material in healthy young men. *Behavioral Neuroscience*, *126*(6), 819-825.

Joëls, M. (2006). Corticosteroid effects in the brain: U-shape it. *Trends in Pharmacological Sciences*, *27*(5), 244-250.

Joëls, M., Pu, Z., Wiegert, O., Oitzl, M. S., & Krugers, H. J. (2006). Learning under stress: How does it work? *Trends in Cognitive Sciences*, *10*(4), 152-158.

Kuhlmann, S., Piel, M., & Wolf, O. T. (2005). Impaired memory retrieval after psychosocial stress in healthy young men. *Journal of Neuroscience*, *25*(11), 2977-2982.

Kuhlmann, S., & Wolf, O. T. (2006). Arousal and cortisol interact in modulating memory consolidation in healthy young men. *Behavioral Neuroscience*, *120*(1), 217-223.

LaBar, K. S., & Cabeza, R. (2006). Cognitive neuroscience of emotional memory. *Nature Reviews Neuroscience*, *7*(1), 54-64.

LaLumiere, R. T., McGaugh, J. L., & McIntyre, C. K. (2017). Emotional modulation of learning and memory: Pharmacological implications. *Pharmacological Reviews*, *69*(3), 236-255.

Larra, M. F., Schulz, A., Schilling, T. M., Ferreira de Sá, D. S., Best, D., Kozik, B., & Schächinger, H. (2014). Heart rate response to post-learning stress predicts memory consolidation. *Neurobiology of Learning and Memory*, *109*, 74-81.

Lindau, M., Almkvist, O., & Mohammed, A. H. (2016). Effects of stress on learning and memory. In *Stress: Concepts, cognition, emotion, and behavior* (pp. 153-160). Academic Press.

Liu, D. L. J., Graham, S., & Zorawski, M. (2008). Enhanced selective memory consolidation following post-learning pleasant and aversive arousal. *Neurobiology of Learning and Memory*, *89*(1), 36-46.

Lovibond, P. F., & Lovibond, S. H. (1995). The structure of negative emotional states: Comparison of the Depression Anxiety Stress Scales (DASS) with the Beck Depression and Anxiety Inventories. *Behaviour Research and Therapy*, *33*(3), 335-343.

Lupien, S. J., Wilkinson, C. W., Briere, S., Ng Ying Kin, N. M., Meaney, M. J., & Nair, N. P. (2002). Acute modulation of aged human memory by pharmacological manipulation of glucocorticoids. *The Journal of Clinical Endocrinology and Metabolism*, *87*(8), 3798-3807.

McCullough, A. M., Ritchey, M., Ranganath, C., & Yonelinas, A. (2015). Differential effects of stress-induced cortisol responses on recollection and familiarity-based recognition memory. *Neurobiology of Learning and Memory*, *123*, 1-10.

McCullough, A. M., & Yonelinas, A. P. (2013). Cold-pressor stress after learning enhances familiarity-based recognition memory in men. *Neurobiology of Learning and Memory*, *106*, 11-17.

McEwen, B. S., & Sapolsky, R. M. (1995). Stress and cognitive function. *Current Opinion in Neurobiology, 5*(2), 205-216.

McGaugh, J. L. (2000). Memory: A century of consolidation. *Science*, *287*(5451), 248-251.

McGaugh, J. L. (2002). Memory consolidation and the amygdala: A systems perspective. *Trends in Neurosciences*, *25*(9), 456-461.

McGaugh, J. L. (2004). The amygdala modulates the consolidation of memories of emotionally arousing experiences. *Annual Review of Neuroscience*, *27*(1), 1-28.

Nater, U. M., Moor, C., Okere, U., Stallkamp, R., Martin, M., Ehlert, U., & Kliegel, M. (2007). Performance on a declarative memory task is better in high than low cortisol responders to psychosocial stress. *Psychoneuroendocrinology, 32*(6), 758-763.

Nielson, K. A., & Lorber, W. (2009). Enhanced post-learning memory consolidation is influenced by arousal predisposition and emotion regulation but not by stimulus valence or arousal. *Neurobiology of Learning and Memory*, *92*(1), 70-79.

Preuß, D., & Wolf, O. T. (2009). Post-learning psychosocial stress enhances consolidation of neutral stimuli. *Neurobiology of Learning and Memory*, *92*(3), 318-326.

Price, D. D., McGrath, P. A., Rafii, A., & Buckingham, B. (1983). The validation of visual analogue scales as ratio scale measures for chronic and experimental pain. *Pain*, *17*(1), 45-56.

Roozendaal, B. (2000). Glucocorticoids and the regulation of memory consolidation. *Psychoneuroendocrinology 25*(3), 213-238.

Roozendaal, B., McEwen, B. S., & Chattarji, S. (2009). Stress, memory and the amygdala. *Nature Review Neuroscience, 10*(6), 423-433.

Sandi, C., & Pinelo-Nava, M. T. (2007). Stress and memory: Behavioral effects and neurobiological mechanisms. *Neural Plasticity,* 78970.

Sarıçam, H. (2018). The psychometric properties of Turkish version of Depression Anxiety Stress Scale-21 (DASS-21) in health control and clinical samples. *Journal of Cognitive-Behavioral Psychotherapy and Research, 7*(1), 19-30.

Schwabe, L., Bohringer, A., Chatterjee, M., & Schachinger, H. (2008). Effects of pre-learning stress on memory for neutral, positive and negative words: Different roles of cortisol and autonomic arousal. *Neurobiology of Learning and Memory*, *90*(1), 44-53.

Schwabe, L., Joëls, M., Roozendaal, B., Wolf, O. T., & Oitzl, M. S. (2012). Stress effects on memory: An update and integration. *Neuroscience and Biobehavioral Reviews, 36*(7), 1740-1749.

Schwabe, L., Wolf, O. T., & Oitzl, M. S. (2010). Memory formation under stress: Quantity and quality. *Neuroscience & Biobehavioral Reviews, 34*(4), 584-591.

Smeets, T., Otgaar, H., Candel, I., & Wolf, O. T. (2008). True or false? Memory is differentially affected by stress-induced cortisol elevations and sympathetic activity at consolidation and retrieval. *Psychoneuroendocrinology, 33*(10), 1378-1386.

Steidl, S., Mohi-Uddin, S., & Anderson, A. K. (2006). Effects of emotional arousal on multiple memory systems: Evidence from declarative and procedural learning. *Learning & Memory*, *13*(5), 650-658.

Trammell, J. P., & Clore, G. L. (2014). Does stress enhance or impair memory consolidation? *Cognition and Emotion, 28*(2), 361-374.

Yonelinas, A. P. (2002). The nature of recollection and familiarity: A review of 30 years of research. *Journal of Memory and Language*, *46*(3), 441-517.

Zoladz, P. R., Kalchik, A. E., Hoffman, M. M., Aufdenkampe, R. L., Lyle, S. M., Peters, D. M., … Rorabaugh, B. R. (2014). ADRA2B deletion variant selectively predicts stress-induced enhancement of long-term memory in females. *Psychoneuroendocrinology, 48*, 111-122.

Zoladz, P. R., Peters, D. M., Cadle, C. E., Kalchik, A. E., Aufdenkampe, R. L., Dailey, A. M., … Rorabaugh, B. R. (2015). Post-learning stress enhances long-term memory and differentially influences memory in females depending on menstrual stage. *Acta Psychologica, 160*, 127-133.

Received June 18, 2022
Revision August 7, 2022
Accepted September 27, 2022