



## Research article

## Examining the effect of stress induction on auditory working memory performance for emotional and non-emotional stimuli in female students

Zahra Khayer<sup>a,\*</sup>, Razieh Saberi Azad<sup>b</sup>, Zahra Torkzadeh Arani<sup>c</sup>, Reza Jafari Harandi<sup>d</sup><sup>a</sup> Educational Sciences & Psychology Department, University of Isfahan, And Shahid Ashrafi Esfahani University, Isfahan, Iran<sup>b</sup> Human Sciences Department, Sepahan Institute of Higher Education, Isfahan, Iran<sup>c</sup> Literature and Human Sciences Faculty, University of Qom, Qom, Iran<sup>d</sup> Educational Sciences Department, Literature and Human Sciences Faculty, University of Qom, Qom, Iran

## ARTICLE INFO

## Keywords:

Stress  
Working memory  
Auditory modality  
Emotional and non-emotional stimuli  
Female

## ABSTRACT

**Background:** Theoretical frameworks have shown that stress might influence working memory in different ways. Previous research has investigated the effect of stress on female's working memory but there is lack of evidence regarding the impact of emotional aspects.**Objectives:** This study examined the effect of stress induction on auditory working memory (AWM) performance among university students for emotional (positive and negative) and non-emotional (neutral) stimuli.**Methods:** A sample of 102 female students at the Universities of Isfahan, Iran was selected using convenience sampling in 2018. Participants completed the demographic information sheets, then, they were randomly assigned into the experimental and control groups. The stress was induced by the Socially Evaluated Cold Pressor Test (SECPT). An n-back task was presented pre and post of stress induction, to evaluate the AWM performance (accuracy and reaction time). The research data were analyzed using mixed-model ANOVA.**Results:** Both accuracy and reaction time (RT) scores were found to be enhanced for positive words in the experimental condition. However, accuracy and RT indices were found to be worsening for negative words in the experimental condition.**Conclusions:** This study supports the idea that stress influences AWM performance depend on emotionally-valenced stimuli, which may help us to better understand the underlying mechanisms of memory processing.

## 1. Introduction

Previous research has shown that stressful and emotional events are among the factors which adversely affect learning and memory with long term consequences (Marin et al., 2019; Roozendaal, 2000). Memory is considered as a mental process that plays a major role in everyday activities. It refers to the brain's capability of encoding, storage, and retrieval of information (Piaget and Inhelder, 2015). Since the introduction of the term "memory" in the 1880's by Hermann Ebbinghaus, many research studies have tried to appropriately categorize this concept (Chai et al., 2018). Knowledge on memory characteristics and functions may help us to better understand how real-life experiences such as emotions, stressors, and relationships might have an influence on it. In other words, our emotional state at the time of an event can affect our ability to memorize its details and might positively influence the accurate recall of related information.

## 1.1. Working memory

Working memory (WM) as a type of human memory has attracted scientists since its introduction in the 1960's (DeSposito & Postle, 2015). WM –active state or immediate memory– involves a set of processes, which are actively responsible for temporarily and simultaneously manipulating, managing, and storing information in complex cognitive tasks. WM uses information from both short-term and long-term memories to group and organize the data properly (Cowan, 2008). Additionally, WM is a mental function that meets immediate needs and is associated with the functions of the dorso-lateral pre-frontal cortex (Barrouillet and Gaillard, 2010). It plays an important role in concentration, learning, and remembering instructions. Cowan (2008) showed that WM capacity is linked to cognitive competencies such as attentional control. Cowan's findings (2008) revealed that WM significantly correlates with cognitive capacity, which in turn is associated with the ability

\* Corresponding author.

E-mail address: [z.khayer62@yahoo.com](mailto:z.khayer62@yahoo.com) (Z. Khayer).

to control attention. Moreover, WM consists of various functions, including the “central executive” that manages and coordinates a number of tasks needed. According to the recent models of WM (Baddeley, 2003; Zimmer, 2008), two types of WM can be distinguished: visual and auditory WMs. Auditory working memory (AWM) is a type of memory that maintains internal speech for verbal comprehension and phonological training (Colman, 2015). It keeps sounds in mind for a short time when they are no longer present in the environment. It is known as “phonological loop” (speech-based information) in Baddeley and Hitch's (2000) model. This type of memory is more associated with the left dorso-lateral pre-frontal cortex (Rodriguez-Jimenez et al., 2009). Moreover, it is also known as the “dorsal stream” or the “where pathway” (Kaiser, 2015). WM is an interesting topic for both basic and clinical studies, thus, it is important to clarify factors that influence its function. Due to lack the of experimental evidence, here, we examined the effect of stress on AWM.

### 1.2. Working memory and stress

Prior research studies have found that WM can be affected by different factors, such as stress (Shields et al., 2019; Shields et al., 2017). Stress (either real or perceived) can influence the balance between the requirements of the situation and the biological, psychological, and social resources of an individual, which may result in dysfunctional mental activities. By definition, stress leads to imbalances in the homeostasis of a person who needs a compatible response (Steckler et al., 2005), and stressors can be either external (like social situations) or internal (like psychological problems). In the current study we applied a social form of stress. In regard to memory, stress can affect its processes (during encoding and retrieval stages) and the related functions (accuracy, efficiency, reaction time). According to the Inverted-U Theory, the response to stress can vary from person to person and from time to time for the same person (Sapolsky, 2015).

Although both high and low levels of stress are associated with changes in memory performance, the ways in which stress relates to both positive and negative effects on working memory is still unclear. For example, stress can facilitate memory performance in a short period of time after learning (Roosendaal, 2000), but it can inhibit memory in a short period of time before learning (Kuhlmann et al., 2005). Some studies have also reported that stress can increase memory performance (Cahill et al., 2003; Smeets et al., 2008; Lukasik et al., 2019). However, other studies have shown that stress can impair memory performance (Buchanan and Tranel, 2008; Colman, 2015; Khayyer et al., 2017).

Luethi et al. (2009) studied the effect of social stress on the different aspects of the human memory (neutral materials for explicit and working memories and emotional stimuli for implicit memory). Their results revealed that verbal WM impairment was related to coping with stress. They also found that stress led to an increase in classical conditioning for negative stimuli and improved spatial WM. Coping with stress activates the hypothalamic-pituitary-adrenal (HPA) axis. Consequently, stress released hormones affect the central nervous system, especially amygdala and hippocampus (these structures are mainly involved in processing cognitive and affective information). These hormones pass through the blood-brain barrier (BBB) due to their lipophilic nature. They soon influence neural and behavioral functions, including memory, via limbic system and its related structures (Roosendaal et al., 2006).

Most people experience anxiety and stress simultaneously with an increased level of vigilance in the nervous system. In the case of anxious people, there is an attentional bias toward negative stimuli, such that these people are more sensitive to stressful and threatening stimuli (Eldar et al., 2008). Eysenck et al. (2007), revealed that anxiety damages cognitive functions by increasing the role of bottom-up processing. The higher the anxiety, the higher impairment in attentional processing.

### 1.3. Working memory and emotion

Human cognition and emotions are closely linked together. Emotions are divided into positive and negative ones with regard to experienced psychophysiological changes. Negative emotions limit thinking, but focus our attention, while positive emotions allow us to think more broadly, which enables creativity and problem-solving (Norman, 2003). Based on neuropsychological theories and studies conducted on amygdala-hippocampus interaction, it is revealed that amygdala is responsible for encoding and storing emotional information (Blanchette and Richards, 2010; Brosch et al., 2010; Levine and Edelstein, 2010). For example, emotions can trigger the information processing by capturing the attention and stimulating the organism. Indeed, amygdala may receive information about the emotional significance of stimuli long before stimuli processing and enhance later perception of emotionally salient events (Phelps, 2004). Moreover, some studies have revealed that amygdala plays a moderating role in consolidating the hippocampal memories by controlling stress hormones (McGaugh and Roozendaal, 2002; Schoofs et al., 2013). Therefore, it can be claimed that emotional valence, besides hormonal activity, is among the main factors influencing information processing because many cognitive processes such as attention, learning, memory, judgment, and interpretation are affected by emotional states (Eysenck and Calvo, 1992). Emotional stimuli may interfere with cognitive processes that underlie memory performance in both clinical and general population. For instance, patients with Traumatic Brain Injury (TBI) show difficulty in recognizing fear, anger, and disgust and perform worse on negative emotions during WM tasks (Rosenberg et al., 2015). In another study by Baker et al. (2016), individuals with chronic pain showed severe impairments on WM and emotional control, especially for negative emotional states. Consistent with “Emotional Impairment Hypothesis”, Garrison and Schmeichel (2019) demonstrated that WM capacity was reduced for emotional words rather than neutral words due to interference with active maintenance of information and attention control.

Moreover, Fairfield et al. (2015) reported that WM might be impaired when a longer list of emotionally valenced words is presented to the participants. These results were explained by lack of executive resources and participants' low scores on the accuracy index (one of the indices used to measure memory). These findings indicate that with an increase in the mental effort, there was a decrease in the amount of resources required for processing of emotions. This was more evident for more complex cognitive tasks. Thus far, we hypothesized that WM function may decrease in relation to emotional stimuli.

### 1.4. Working memory and gender specific studies

As we mentioned above, stress has been shown to influence WM. However, women's cognitive functions have not received much attention. Rodent studies have reported that female rats show stronger WM deficits after stressful events (Shansky et al., 2006). Although most studies on effects of stress on WM have examined men (Oei et al., 2009; Schoofs et al., 2009; Schoofs et al., 2008), there is limited evidence regarding female participants. Likewise, fewer studies have investigated the auditory type of WM. In addition, according to the controversial nature of findings in this field of study, one of the purposes of the current research was to investigate young educated female participants. It may help the scientists to find more information about the underlying mechanisms of WM in women. With regard to previous studies, women employ different psychological and physiological patterns of stress responses. For example, women suffer more stress than men, and their coping strategy is more emotion-based than problem-focused (Patel et al., 2008). Furthermore, cortisol response to stress is at lower levels in women than men and the hypothalamic-pituitary-adrenal (HPA) axis response is slower among women due to the levels of the female sex hormones (Kudielka and Kirschbaum, 2005).

The effects of stress on learning and memory have been much investigated in human and animal studies but few studies have investigated AWM performance (including accuracy and reaction time) in a non-clinical population. Furthermore, studies have reported contradictory (for instance in the study of Roozendaal, 2000, stress increased memory capacity and in the study of Kuhlmann et al., 2005, stress decreased memory capacity) or ambiguous results in this regard. Therefore, this study aimed to determine the effect of stress induction on AWM among the university students by focusing on emotionally-valenced stimuli. In addition, we hypothesized that acute social stress may impair the function of negative stimuli while it improves positive stimuli. This paper attempts to increase the psychologist's knowledge about the relationship between AWM and understanding emotional speech in healthy adult women. This paper also examines current literature on AWM and provides a brief overview about working memory associated with perceived stress.

## 2. Methodology

### 2.1. Participants

The statistical population consisted of all the students of three universities in Isfahan city, during the academic year 2018–2019. A sample of 102 female students was selected through convenience (and also purposeful) sampling method. This sample size was determined by G-power software. With regard to similar studies (Quesada et al., 2012; Schoofs et al., 2008), effect size (Cohen's  $d = .5$ ), Statistical power ( $1-\beta = .8$ ), and allowable error ( $\alpha = .05$ ) were determined. The inclusion criteria were: Iranian nationality, being female, aged between 18 and 35 years, being university student, no drugs of abuse, no mental and physical problems, not using any medication (applying the 12-item General Health Questionnaire). All female participants were free of hormonal contraception and were examined outside of menstrual cycle (self-report). The mean age of the participants was 23.53 ( $SD = 4.1$ ) years. The participants were recruited through printed advertisements on notice boards in different departments at three universities. Moreover, the participants were selected from different educational levels and fields of study and were randomly assigned into two groups-with and without stress. All of the participants signed the consent forms, and the researcher ensured to maintain confidentiality of information collected from them. The study was conducted in accordance with the declaration of Helsinki and the Research Ethics and Governance Committee at University of Isfahan approved the study protocol.

### 2.2. Measures

#### 2.2.1. N-back task

The N-back task was first developed by Kirchner (1958). The computerized version of the n-back task (Jaeggi et al., 2007) was used in this study to measure the WM capacity. Since the n-back task can be used for both storing and manipulating information, it is widely used in measuring WM capacity (Chen et al., 2008). In this test, a sequence of auditory stimuli on a computer monitor was administered to the participants. Based on 1-back task, the participants were required to tap the key 1 in case of the similarity of any stimulus with the previous stimulus and tap the key 0 in case of any dissimilarity between them. Stimuli were presented at an interval of 2 s. The validity of the n-back task (for all three types of emotions) was determined by the convergent validity, which is one type of construct validity. To do so, the digit span short-term memory test (Wechsler, 1997) and n-back task were administered to the participants (both were in computerized version), and the correlation coefficient of negative, positive, and neutral stimulus were .71, .81, and .85, respectively. Moreover, the reliability of the computerized auditory n-back task has been reported .83 applying test-retest method on ten volunteer students.

The test-retest reliability was used to determine the reliability of the n-back task. To do so, the n-back task was administered to a volunteering group of 10 same-age students with one week interval. The Pearson correlation coefficient of the scores of these participants was .83, indicating a good reliability. In the current study, we used 100 Persian words (Abbasi, 2011) including equal numbers of neutral (such as table, light, coach), positive (such as love, spring, holiday), and negative (such as death, evil, failure) valence in line with the research goals. The researchers-made auditory n-back task was applied in this study and took 7 min to complete. Additionally, the reaction time and response accuracy (AWM performance indices) measures were recorded.

#### 2.2.2. The Socially Evaluated Cold Pressor Test (SECPT)

The participants in the experimental condition were asked to immerse their non-dominant hand into ice-cold (0–2 °C) water for 3 min (with videotaping). The participants in the control condition were asked to immerse their hands (non-dominant) in room-temperature (35–37 °C) water (without videotaping). Videotaping was used as an element to induce stress. Tolerance time was recorded, then, the cold immersion participants rated the intensity of the felt pain during the test. The Cold Pressor Test (CPT) is a cardiovascular test associated with experimental pain induction. This test is widely used in stress induction studies, investigating the effect of stress on a variety of stimuli. It significantly activates the autonomic nervous system and also the Hypothalamic–pituitary–adrenal (HPA) axis (McGrath, 2006; Schwabe et al., 2008). The findings of the previous studies have revealed that CPT is effective in learning tasks related to WM performance (Duncko et al., 2009; Duncko et al., 2007).

#### 2.2.3. The 12-item general health Questionnaire-12 (GHQ-12)

GHQ-12 was developed by Goldberg in the 1970s. In Persian population, reliability analysis demonstrated acceptable result (Cronbach's alpha coefficient = .87). Convergent validity showed a significant negative association between the GHQ-12 and global quality of life scores ( $r = -.56$ ,  $P < .0001$ ) (Montazeri et al., 2003).

### 2.3. Study design

This study is a quasi-experimental pretest-posttest control-grouped research. The within subject factor, i.e. AWM performance, was measured in terms of accuracy and RT with regard to emotional-valenced stimuli with two levels (emotional and non-emotional). The between subject factor of the study was condition (experimental or control). Participants were randomly assigned into experimental and control groups. In “experimental” condition we had stress induction and in “control” condition there was no stress induction.

### 2.4. Procedure

All of the participants involved in the experiment were separately tested and were asked to refrain from eating, drinking, and smoking one hour before the experiment. Before the start of the experiment, the participants completed the demographic information sheet, general health questionnaire, and signed the informed consent form. Then, they were interviewed to disclose whether they had a history of any special physical or mental disease, and the intake of any special pills. Participants were compensated for their time with monetary payment. After screening phase, they were randomly assigned into the experimental and control groups by flipping a coin. Then, n-back AWM was performed as pre-test for both conditions. Afterwards, participants in the experimental condition underwent the stress induction process by immersing their right hands into ice-cold water for 3 min while being videotaped. At the same time, a distracting sound was played in the environment (white noise) as mentioned in SECPT protocol. However, participants in control condition immersed their hands into room-temperature water without being videotaped, listening to the distracting sound, and being watched by an

examiner (they received no intervention). After two minutes the n-back task was administered in post-test stage to the all participants (when the stress levels reached its peak). Participants were asked to use their index finger of their dominant hands and press NumPad 1 if the word was similar to the previous one and press the NumPad 2 if the word was not similar to the previous one. To prevent the practice effect, a parallel auditory version of the test was administered to the participants in post-test stage.

### 2.5. Statistical analysis

The data were analyzed by the 2 (condition) x 2 (time) x 2 (emotional valence) mixed-model ANOVA. It was performed with Condition (experimental vs. control) as between-subject factor and WM indices (accuracy pre-test vs. accuracy post-test and RT pre-test vs. RT post-test) as within-subject factors. The response accuracy and RT as the indices of AWM performance were measured pre and post in both experimental and control conditions. Stress condition was assumed as between subject factor. The data were analyzed applying SPSS version 23.

## 3. Results

### 3.1. Demographic data

The demographic information is presented in Table 1. Data reported in Table 1, demonstrated that most of the participants were single (66%), aged between 18 to 23 years old (84%), studying in bachelor degree (69%), and have no job (75%). All of them were university students who lived in Isfahan. The mean age of the participants was  $22.8 \pm 5.01$  years.

### 3.2. Descriptive statistics

Mean and standard deviation of AWM performance are reported in Table 2. According to Table 2, the mean scores of both accuracy and RT were greater for the positive words while the mean scores of these aforementioned indices were lesser for the negative words. In addition, AWM indices did not show any changes with regard to the neutral words.

### 3.3. Model assumptions for mixed model ANOVA

All of the ANOVA assumptions such as normality, multicollinearity, homogeneity of variance, and sphericity were checked before carrying out the analysis. The results demonstrated that all study variables were in

**Table 1.** Demographic information.

| Variable          | Frequency | Percent (%) |
|-------------------|-----------|-------------|
| Age               |           |             |
| 18–23             | 86        | 84%         |
| 24–29             | 10        | 9%          |
| 30–35             | 6         | 7%          |
| Marital status    |           |             |
| Single            | 68        | 66%         |
| Married           | 32        | 31%         |
| Divorced          | 2         | 5%          |
| Educational level |           |             |
| Associate Degree  | 6         | 7%          |
| Bachelor          | 71        | 69%         |
| Master            | 21        | 20%         |
| PhD               | 4         | 6%          |
| Participants' job |           |             |
| No job            | 77        | 75%         |
| Formal job        | 5         | 8%          |
| Informal job      | 20        | 19%         |

normal distribution applying Kolmogorov–Smirnov test. Furthermore, Levene's test was not significant for none of the variables. Also, dependent variables were not significantly associated. Moreover, Mauchly's test of sphericity was not significant.

### 3.4. Analysis of variance of AWM performance indices

This section presents the results of the mixed model ANOVA for AWM performance indices, including accuracy and RT. These indices consisted of response accuracy index, including accurate response scores of the participants to the target stimuli, and RTs (reaction time of the participants to the target stimuli). Before carrying out the analysis, ANOVA prerequisites were performed. The Shapiro-Wilk test was used to determine the normality of the distribution of the scores. The results demonstrated the normal distribution of the scores in the pre-test and post-test stages. The equality of variances assumption was analyzed by the Levene test. The results revealed that the assumption was verified for all the variables. The ANOVA results for the main effect of our within-groups factor were significant. The ANOVA results for our between-groups variable (condition) showed significant changes.

A 2 (Time) x 2 (condition) x 2 (emotional valence) mixed-model ANOVA revealed that the main effect for condition was significant  $F(6,89) = 14.7, p < .05$ . Thus, experimental condition was different in the task scores of WM compared to control condition. A significant main effect for Time was obtained,  $F(2,36) = 8.59, p < .05$ . WM indices after the stress induction were significantly different than before the stress. Furthermore, a significant main effect for emotional valence was observed,  $F(3,241) = 9.30, p < .05$ .

Moreover, a significant Condition x Emotional valence was also obtained,  $F(2,86) = 7.67, p < .05$ . With regard to this result, accuracy and RT of emotional words (positive and negative) were statistically significant in experimental condition in comparison to “no stress” condition. However, no significant changes were found with regard to non-emotional words between experimental and control conditions.

## 4. Discussion and conclusion

This study investigated the effect of stress induced by SECPT on AWM performance of the participants under two different conditions. Our findings revealed that, stress induction lead to alter AWM performance in experimental condition, i.e. the number of accurate responses and reaction time were increased. Precisely, both accuracy and reaction time (RT) measures were found to be better for positive words in experimental condition. However, accuracy and RT indices were found to be worsening for negative words in the experimental condition. As regards negative words, our findings are in line with Moran's (2016) and Khayyer et al. (2017) studies that demonstrated that increased stress and anxiety are associated with weaker WM performance (emotional impairment hypothesis). It may be justified by the fact that stress increases the likelihood of cognitive errors due to possible impairments in individuals' attention and concentration (Farhad Beigi et al., 2011). It has been exhibited that during stress, controlled attention resources are decreased as they are assigned to the potential threat (Klein and Boals, 2001). Negative stimuli increases arousal in nervous system (arousal hypothesis) and arousal causes to shift the processing information from hippocampus to amygdala, which in turn impairs memory associations (Madan et al., 2017). On the other hand, processing negative words requires greater sorting cost in comparison to positive or neutral words (Joormann et al., 2011). Furthermore, in line with a study by Glazebrook et al. (2016), auditory modality was greatly influenced by non-relevant environmental visual stimuli. In addition, mental efforts of the participants in perceiving several positive, negative, and neutral words and simultaneously deciding whether they were repeated or not, in spite of the distracting sound in the environment, may be another explanation for decreased AWM performance under stress (Hammond, 2000).

**Table 2.** Mean and standard deviation of study variables in both conditions.

| Variables           | Experimental condition |             | Control condition |             |
|---------------------|------------------------|-------------|-------------------|-------------|
|                     | pre                    | post        | pre               | post        |
|                     | M ± Sd                 | M ± Sd      | M ± Sd            | M ± Sd      |
| Accuracy (Positive) | 4.9 ± .41              | 8.34 ± .42  | 4.3 ± .28         | 4.04 ± .29  |
| Accuracy (Negative) | 4.02 ± .36             | 1.5 ± .37   | 3.77 ± .38        | 3.55 ± .39  |
| Accuracy (Neutral)  | 3.34 ± .3              | 4.06 ± .31  | 3.53 ± .45        | 3.8 ± .46   |
| RT (Positive)       | 13.04 ± .75            | 9.52 ± .77  | 13.27 ± .46       | 12.97 ± .47 |
| RT (Negative)       | 13.16 ± .12            | 18.21 ± .12 | 12.43 ± .24       | 12.66 ± .25 |
| RT (Neutral)        | 12.18 ± .13            | 13.31 ± .14 | 12.15 ± .29       | 12.48 ± .3  |

M = mean, Sd = standard deviation.

Italics are statistically significant.

In addition, our findings revealed that accuracy scores of negative words were decreased among participants in experimental condition and this is in line with Schoofs et al. (2013). Evidence suggests that higher attentional sensitivity during processing of negative items could impair memory function. On the other hand, women usually use more threatening appraisal under stressful situations and view those situations as unchangeable, which in turns might lead to more impairments in cognitive performance (Banyard and Graham-Bermann, 1993). Moreover, different factors such as different times (mornings vs. afternoons) for measuring memory capacity after stress induction (given the rhythmic nature of cortisol release, which is higher in the morning than in the afternoon) (Elzinga and Roelofs, 2005) and different cognitive loads correlated with test items (high vs. low) (Oei et al., 2006) may be differently involved in WM impairment. We suggest setting more similar experimental conditions for all the participants in future studies would be useful.

With regard to positive words, our findings are not in accordance with the results of Joëls et al. (2006) and Lukasik et al. (2019). Our results revealed that participants scored better in terms of response accuracy index for emotionally positive stimuli. This finding may be justified by the fact that emotionally arousing experiences tend to be well remembered (Roozendaal, 2002). In addition, Zimmerman and Kelley (2010) found that positive words were remembered better than neutral words (valence hypothesis). In spite of negative stimuli, positive ones are recalled with accordance to the degree of pleasantness, which leads to greater general processing (Fredrickson and Branigan, 2005). However, anxiety or stress might lead to more focus on negative stimuli which in turns lead to limited attentional control (Eysenck et al., 2007).

Moreover, the uses of the right hand in AWM test and consequently the processing of the incoming information by the left hemisphere of the brain (cross wiring of the hemispheres), which is responsible for processing positive emotions, (see Davidson's theory of mind) may account for this. This finding is consistent with Luethi's et al. (2009) who studied the effect of social stress on WM in healthy people. They revealed that auditory-verbal WM impairment was related to stress. Moreover, stress led to increased classical conditioning for negative stimuli and improved spatial WM performance. In sum, they found that acute stress impairs WM performance.

Furthermore, RTs of positive words were less than that of non-emotional stimuli, while negative words were associated with longer RTs. This implies a difference in the degree of activation of the autonomic nervous system based on the emotional level of the stimuli. In the case of negative stimuli, since amygdala (the center for processing emotions in the brain) is more activated, reaction time is increased (Schwabe et al., 2008). This finding is consistent with the findings of Cornelisse et al. (2010).

Moreover, the lack of effect of stress on AWM performance of the positive stimuli may be explained by being in the first versus second half of the menstrual cycle of our participants (Tersman et al., 1991). Thus, we suggest to consider this as a between subject factor in future studies. For instance, Gasbarri et al. (2008) studied WM performance for emotional facial expressions in young women in different phases of the menstrual cycle. They found that high levels of estradiol in the follicular phase may have a negative effect on WM performance of the women, with regard to emotional stimuli processing. Moreover, the percentage of making errors retrieving test items was significantly higher for the emotional facial expressions of sadness and disgust in the follicular phase, in comparison to the menstrual phase.

With regard to neutral words, our findings revealed no significant differences between experimental and control condition. These results are in line with Mammarella et al. (2013) study. They showed that WM capacity increases in emotional information because emotional stimuli enhance processing resources and attract attention. Furthermore, in addition to emotionally-based information in processing auditory information in WM, bigger brain's network including auditory cortex, hippocampus, and frontal area are active. According to emotional enhancement hypothesis, emotional information attracts attention and organizes processing resources; thus far easier to store in working memory relative to neutral stimuli.

#### 4.1. Conclusions

Discovering the ways in which stress influences women's memory might help us understand the mechanisms responsible for the link between stressor factors and memory functions. For instance, one can investigate whether a biological mechanism, such as gender, influences memory retrieval of auditory items. In addition to female memory characteristics, type and intensity of stressor, including emotional valence and arousal, might have different effects on memory processing strategies. Moreover, we conclude that all the above-mentioned factors are essential to construct a more comprehensive model that defines the role of stress in memory function.

This implies that strategies that enhance memory competencies in relation to emotional stimuli are likely to increase cognitive functions in general. For example, some positively-valenced material could serve as a buffer for other positive emotions when facing distressing social events. Finally, the authors suggest there is a need to review the concepts such as social roles, individual life style, hormonal state of women experiencing stress. Carrying out mediating analysis may also be helpful in finding more data regarding the fundamental process of memory functions under stress.

These results support the potential utility of individualized cognitive promotion intervention for women who play different roles in work,

family, and social situations, in order to improve quality of mental life by focusing on gender differences.

## 5. Study limitations

Although this study provides important insights into the relationship between cognition and emotion, student-based population, only female subjects, and ignoring the different subcultures denote some limitations. Thus, replication of the study in other and bigger samples and different cultures is necessary. In addition, it is recommended that researchers examine whether implicit variables, including endocrine and nervous systems, do mediate memory processing under stress for different emotional stimuli.

## Declarations

### Author contribution statement

Zahra Khayyer: Conceived and designed the experiments; Wrote the paper.

Razieh Saberi Azad: Performed the experiments; Wrote the paper.

Zahra Torkzadeh Arani: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data.

Reza Jafari Harandi: Conceived and designed the experiments; Analyzed and interpreted the data.

### Funding statement

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

### Data availability statement

Data will be made available on request.

### Declaration of interests statement

The authors declare no conflict of interest.

### Additional information

No additional information is available for this paper.

## Acknowledgements

We would also like to show our gratitude to those who helped us for sharing their pearls of wisdom with us during the course of this research.

## References

- Abbasi, S., 2011. Differences between Two Brain Hemispheres in Processing Emotional Stimulus between Persian and English Languages. Institute for Cognitive Science Studies, Master thesis, Tehran, Iran.
- Baddeley, A.D., 2003. Working memory: looking back and looking forward. *Nat. Rev. Neurosci.* 4, 829–839.
- Baddeley, A.D., Hitch, G.J., 2000. Development of working memory: should the Pascual-Leone and the Baddeley and Hitch models be merged? *J. Exp. Child Psychol.* 77 (2), 128–137.
- Baker, K.S., Gibson, S., Georgiou-Karistianis, N., Roth, R.M., Giummarra, M.J., 2016. Everyday executive functioning in chronic pain: specific deficits in working memory and emotion control, predicted by mood, medications, and pain interference. *Clin. J. Pain* 32 (8), 673–680.
- Banyard, V.L., Graham-Bermann, S.A., 1993. A gender analysis of theories of coping with stress. *Psychol. Women Q.* 17 (3), 303–318.
- Barrouillet, P., Gaillard, V. (Eds.), 2010. Cognitive Development and Working Memory: A Dialogue between Neo-Piagetian Theories and Cognitive Approaches. Psychology Press.
- Blanchette, I., Richards, A., 2010. The influence of effect on higher level cognition: a review of research on interpretation, judgement, decision making and reasoning. *Cognit. Emot.* 24 (4), 561–595.

- Brosch, T., Pourtois, G., Sander, D., 2010. The perception and categorization of emotional stimuli: a review. *Cognit. Emot.* 24 (3), 377–400.
- Buchanan, T.W., Tranel, D., 2008. Stress and emotional memory retrieval: effects of sex and cortisol response. *Neurobiol. Learn. Mem.* 89, 134–141.
- Cahill, L., Gorski, L., Le, K., 2003. Enhanced human memory consolidation with post-learning stress: interaction with the degree of arousal at encoding. *Learn. Mem.* 10, 270–274.
- Chai, W.J., Abd Hamid, A.I., Abdullah, J.M., 2018. Working memory from the psychological and neurosciences perspectives: a review. *Front. Psychol.* 9, 401.
- Chen, Y.N., Mitra, S., Schlaghecken, F., 2008. Sub-processes of working memory in the N-back task: an investigation using ERPs. *Clin. Neurophysiol.* 119 (7), 1546–1559.
- Colman, A.M., 2015. A Dictionary of Psychology. Oxford Quick Reference, UK.
- Cornelisse, S., Van Stegeren, A.H., Joels, M., 2010. Implications of psychological stress on memory formation in a typical male versus female students sample. *Psychoneuroendocrinology* 36, 569–578.
- Cowan, N., 2008. What are the differences between long-term, short-term, and working memory? *Prog. Brain Res.* 169, 323–338.
- D'Esposito, M., Postle, B.R., 2015. The cognitive neuroscience of working memory. *Annu. Rev. Psychol.* 66, 115–142.
- Duncko, R., Cornwell, B., Cui, L., Merikangas, K.R., Grillon, C., 2007. Acute exposure to stress improves performance in trace eye blink conditioning and spatial learning tasks in healthy men. *Learn. Mem.* 14, 329–335.
- Duncko, R., Johnson, L., Merikangas, K., Grillon, C., 2009. Working memory performance after acute exposure to the cold pressor stress in healthy volunteers. *Neurobiol. Learn. Mem.* 91 (4), 377–381.
- Eldar, S., Ricon, T., Bar-Haim, Y., 2008. Plasticity in attention: implications for stress response in children. *Behav. Res. Ther.* 46, 450–461.
- Elzinga, B.M., Roelofs, K., 2005. Cortisol-induced impairments of working memory require acute sympathetic activation. *Behav. Neurosci.* 119, 98–103.
- Eysenck, M.W., Calvo, M.G., 1992. Anxiety and performance: the processing efficiency theory. *Cognit. Emot.* 6 (6), 409–434.
- Eysenck, M.W., Derakshan, N., Santos, R., Calvo, M.G., 2007. Anxiety and cognitive performance: attentional control theory. *Emotion* 7 (2), 336–353.
- Fairfield, B., Mammarella, N., Di Domenico, A., Palumbo, R., 2015. Running with emotion: when affective content hampers working memory performance. *Int. J. Psychol.* 50 (2), 161–164.
- Farhad Beigi, P., Bagherian, F., Khorrami Banaraki, A., 2011. The effect of stress on accuracy and speed of judgment. *J. Soc. Psychol. Res.* 1 (2), 69–78 (Persian).
- Fredrickson, B.L., Branigan, C., 2005. Positive emotions broaden the scope of attention and thought-action repertoires. *Cognit. Emot.* 19, 313–322.
- Garrison, K.E., Schmeichel, B.J., 2019. Effects of emotional content on working memory capacity. *Cognit. Emot.* 33 (2), 370–377.
- Gasbarri, A., Pompili, A., d' Onofrio, A., Chfariello, A., Tavares, C.M., Tomaz, 2008. Working memory for emotional facial expressions: role of the estrogen in young women. *Psychoneuroendocrinology* 33, 964–972.
- Glazebrook, C.M., Welsh, T.N., Tremblay, L., 2016. The processing of visual and auditory information for reaching movements. *Psychol. Res.* 80 (5), 757–773.
- Hammond, K.R., 2000. Judgment under Stress. Oxford University Press, New York.
- Jaeggi, S.M., Buschkuhl, M., Etienne, A., Ozdoba, C., Perrig, W.J., Nirkkio, A.C., 2007. On how high performers keep cool brains in situations of cognitive overload. *Cognit. Affect Behav. Neurosci.* 7 (2), 7589.
- Joëls, M., Pu, Z., Wiegert, O., Oitzl, M.S., Krugers, H.J., 2006. Learning under stress: how does it work? *Trends Cognit. Sci.* 10, 152–158.
- Joomann, J., Levens, S.M., Gotlib, I.H., 2011. Sticky thoughts: depression and rumination are associated with difficulties manipulating emotional material in working memory. *Psychol. Sci.* 22, 979–983.
- Kaiser, J., 2015. Dynamics of auditory working memory. *Front. Psychol.* 6, 613.
- Khayyer, Z., Nejati, V., Fathabadi, J., 2017. Stress induction and visual working memory performance: the effects of emotional and non-emotional stimuli. *Biotechnol. Health Sci.* 4 (2), e57652.
- Kirchner, W.K., 1958. Age differences in short-term retention of rapidly changing information. *J. Exp. Psychol.* 55 (4), 352–358.
- Klein, K., Boals, A., 2001. The relationship of life event stress and working memory capacity. *Appl. Cogn. Psychol.* 15, 565–579.
- Kudielka, B.M., Kirschbaum, C., 2005. Sex differences in HPA axis responses to stress: a review. *Biol. Psychol.* 69 (1), 113–132.
- Kuhlmann, S., Piel, M., Wolf, O.T., 2005. Impaired memory retrieval after psychosocial stress in healthy young men. *J. Neurosci.* 25 (11), 2977–2982.
- Levine, L.J., Edelman, R.S., 2010. Emotion and memory narrowing: a review and goal-relevance approach. In: De Houwer, J., Hermans, D. (Eds.), *Cognition and Emotion: Reviews of Current Research and Theories*. Psychology Press; US, New York, NY, US, pp. 169–210.
- Luethi, M., Meier, B., Sandi, C., 2009. Stress effects on working memory, explicit memory, and implicit memory for neutral and emotional stimuli in healthy men. *Front. Behav. Neurosci.* 2, 1–9.
- Lukasik, K.M., Waris, O., Soveri, A., Lehtonen, M., Laine, M., 2019. The relationship of anxiety and stress with working memory performance in a large non-depressed sample. *Front. Psychol.* 10, 44.
- Madan, C.R., Fujiwara, E., Caplan, J.B., Sommer, T., 2017. Emotional arousal impairs association-memory: roles of amygdala and hippocampus. *Neuroimage* 156, 14–28.
- Mammarella, N., Borella, E., Carretti, B., Leonardi, G., Fairfield, B., 2013. Examining an emotion enhancement effect in working memory: evidence from age-related differences. *Neuropsychol. Rehabil.* 23, 416–428.
- Marin, M.F., Raymond, C., Lupien, S.J., 2019. Memory and stress. In: Fink, G. (Ed.), *Stress: Physiology, Biochemistry, and Pathology*. Academic Press, USA, pp. 69–78.

- McGaugh, J.L., Roozendaal, B., 2002. Role of adrenal stress hormones in forming lasting memories in the brain. *Curr. Opin. Neurobiol.* 12, 205–210.
- McGrath, J.J., 2006. Variations in the incidence of schizophrenia: data versus dogma. *Schizophr. Bull.* 32 (1), 195–197.
- Montazeri, A., Harirchi, A.M., Shariati, M., Garmaroudi, G., Ebadi, M., Fateh, A., 2003. The 12-item General Health Questionnaire (GHQ-12): translation and validation study of the Iranian version. *Health Qual. Life Outcome* 1 (1), 66.
- Moran, T.P., 2016. Anxiety and working memory capacity: a meta-analysis and narrative review. *Psychol. Bull.* 142, 831–864.
- Norman, D.A., 2003. Attractive Things Work Better. *Emotional Design: Why we Love (Or Hate) Everyday Things*. Basic Books, New York.
- Oei, N.Y., Everaerd, W.T., Elzinga, B.M., van Well, S., Bermond, B., 2006. Psychosocial stress impairs working memory at high loads: an association with cortisol levels and memory retrieval. *Stress* 9, 133–141.
- Oei, N.Y., Tollenaar, M.S., Spinhoven, P., Elzinga, B.M., 2009. Hydrocortisone reduces emotional distracter interference in working memory. *Psychoneuroendocrinology* 34 (9), 1284–1293.
- Patel, P.D., Katz, M., Karszen, A.M., Lyons, D.M., 2008. Stress-induced changes in corticosteroid receptor expression in primate hippocampus and prefrontal cortex. *Psychoneuroendocrinology* 33 (3), 360–367.
- Phelps, E.A., 2004. Human emotion and memory: interactions of the amygdala and hippocampal complex. *Curr. Opin. Neurobiol.* 14 (2), 198–202.
- Piaget, J., Inhelder, B., 2015. *Memory and Intelligence (Psychology Revivals)*. Psychology Press, USA.
- Quesada, A.A., Wiemers, U.S., Schoofs, D., Wolf, O.T., 2012. Psychosocial stress exposure impairs memory retrieval in children. *Psychoneuroendocrinology* 37 (1), 125–136.
- Rodriguez-Jimenez, R., Avila, C., Garcia-Navarro, C., Bagny, A., Aragon, A.M., Ventura-Campos, N., Martinez-Gras, I., Forn, C., Ponce, G., Rubio, G., Jimenez-Arriero, M.A., Palomo, T., 2009. Differential dorsolateral prefrontal cortex activation during a verbal n-back task according to sensory modality. *Behav. Brain Res.* 20, 299–302.
- Roozendaal, B., 2000. Glucocorticoids and the regulation of memory consolidation. *Psychoneuroendocrinology* 25 (3), 213–238.
- Roozendaal, B., 2002. Stress and memory: opposing effects of glucocorticoids on memory consolidation and memory retrieval. *Neurobiol. Learn. Mem.* 78, 578–595.
- Roozendaal, B., Okuda, S., de Quervain, D.J., McGaugh, J.L., 2006. Glucocorticoids interact with emotion induced noradrenergic activation in influencing different memory functions. *Neuroscience* 138 (3), 901–910.
- Rosenberg, H., Dethier, M., Kessels, R.P., Westbrook, R.F., McDonald, S., 2015. Emotion perception after moderate–severe traumatic brain injury: the valence effect and the role of working memory, processing speed, and nonverbal reasoning. *Neuropsychology* 29 (4), 509.
- Sapolsky, R.M., 2015. Stress and the brain: individual variability and the inverted-U. *Nat. Neurosci.* 18, 1344–1346.
- Schoofs, D., Preuß, D., Wolf, O.T., 2008. Psychosocial stress induces working memory impairments in an n-back paradigm. *Psychoneuroendocrinology* 33 (5), 643–653.
- Schoofs, D., Wolf, O.T., Smeets, T., 2009. Cold pressor stress impairs performance on working memory tasks requiring executive functions in healthy young men. *Behav. Neurosci.* 123 (5), 1066.
- Schoofs, D., Pabst, S., Brand, M., Wolf, O.T., 2013. Working memory is differentially affected by stress in men and women. *Behav. Brain Res.* 241, 144–153.
- 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. *Neurobiol. Learn. Mem.* 90, 44–53.
- Shansky, R.M., Rubinow, K., Brennan, A., Arnsten, A.F., 2006. The effects of sex and hormonal status on restraint-stress-induced working memory impairment. *Behav. Brain Funct.* 2 (1), 8.
- Shields, G.S., Doty, D., Shields, R.H., Gower, G., Slavich, G.M., Yonelinas, A.P., 2017. Recent life stress exposure is associated with poorer longterm memory, working memory, and self-reported memory. *Stress* 20, 598–607.
- Shields, G.S., Ramey, M.M., Slavich, G.M., Yonelinas, A.P., 2019. Determining the mechanisms through which recent life stress predicts working memory impairments: precision or capacity? *Stress* 1–6.
- 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.
- Steckler, T., Kalin, N.H., Reul, J.H.M., 2005. *Handbook of Stress and the Brain Part 1: the Neurobiology of Stress*. Elsevier.
- Tersman, Z.I.T.A., Collins, A., Eneroth, P., 1991. Cardiovascular responses to psychological and physiological stressors during the menstrual cycle. *Psychosom. Med.* 53 (2), 185–197.
- Wechsler, D., 1997. *Wechsler Adult Intelligence Scale—Administration and Scoring Manual*, third ed. The Psychological Corporation, San Antonio, TX.
- Zimmer, H.D., 2008. Visual and spatial working memory: from boxes to networks. *Neurosci. Biobehav. Rev.* 32, 1373–1395.
- Zimmerman, C.A., Kelley, C.M., 2010. “I’ll remember this!” Effects of emotionality on memory predictions versus memory performance. *J. Mem. Lang.* 62, 240–253.