Learning and Memory under Stress: A Review Study with Evaluation Techniques

Abdelhadi Alzyoud1, Omar AlShorman2, Mahmoud Masadeh3, Fahad Alkahtani4, Ra‘ed Bani Abdelrahman2

ABSTRACT
In recent years, stress becomes a global problem faced by human beings at all stages of their life. It represents a serious problem and affects their lifestyle. Academic life is a fertile environment for stress forming due to the different stressing factors faced by students during all stages and to the various cognitive functions applied to acquire the new knowledge. In this review, stress impacts and effects on learning and memory are highlighted. Learning and memory are vital in students’ achievement and improvement as they are part of the cognitive functions of the brain. Academic stress influences these two main skills, and it may impair the three stages of learning and memory: encoding, consolidation and retrieval. Thus, in this work, the proposed literature reviews the effects of academic stress on learning and memory cognitive functions based on six models including functional near-infrared spectroscopy (fNIRS), electroencephalogram (EEG), magnetic resonance imaging (MRI), electrocardiogram (ECG), behavioral analysis and multiple models. Finally, the challenges are highlighted, and further studies are proposed.

INTRODUCTION
Learning and memory performances are affected by stress which is caused due to psychophysiological responses. The effects of stress on learning and working memory are not homogenous [1]. Stress is reported as a cause of impaired memory performance ([2], [3], [4]). On the other hand, some other researchers suggested that no effects of stress on learning and working memory and it could have a positive influence on them ([5], [6], [7]). Stress affects the human nervous system, and this led to changes in the structures of the brain’s parts [8]. The atrophy of the brain mass and weight could be also affected by stress [9]. The brain structural changes cause different responses to stress and working memory [8]. The duration and level of stress also determine the amount and intensity of the structural changes of the brain [8].

Academic environment is also affected by stress and this influence academic achievement of students and their abilities to learn and memorize the new acquired knowledge. Students in all stages of learning, not only adult students, are affected by the sequences of stress even at primary stage of school [10]. Academic stress may cause depression behavioral problems and anxiety among students [11], [12]. Future expectation, failure phobia, recognizing problems and memory retrieval were results of stress [13].

The academic stress has a noticeable effect on cognitive functions, which refer to various mental capabilities including thinking, learning, remembering, attention, reasoning, decision making and problem solving. Attention is affected by stress because it distracts the awareness during the stage of catching new knowledge [14]. Stress restricts the memory during the task of encoding the information and recalling it [15]. Focusing is also affected by stress because it may scatter students’ thoughts. Decision making, problems solving and judgments as parts of the cognitive function are influenced by stress in many different ways. Learning and memory are affected by stress positively or negatively. The influence depends on the learning context, stressors or the learning task itself. Stress may occur in any stage of learning acquisition “encoding”, consolidation and retrieval. In [16], researchers suggested if the stress starts at the encoding stage it will either impair or enhance the acquisition. Source of stress, stressors intensity, stressors duration and stressors timing are factors determining the level of the influence of stress in memory and learning [17]. Lately, the curfew and the lock down announced by governments and health organizations because of the pandemic of Covid-19 charged students with new stressors. These stressors may lead to anxious student, sleeping problems and low achievement. Furthermore, academic performance and learning abilities are affected. Thus, it is worth to study them in ordered to provide and give effective solutions [18].

The main contribution of the proposed study is to review the effects of academic stress on learning and memory cognitive functions based on six models including functional near-infrared spectroscopy (fNIRS), electroencephalogram (EEG), magnetic resonance imaging (MRI), electrocardiogram (ECG), behavioral analysis and multiple models. Finally, the challenges and possible future trends are highlighted.

METHODOLOGY AND MEASUREMENTS
The pandemic of COVID-19 has affected all people and changed everything in their life’s. The way people live and interact, how they work and communicate and how they move, and travel are examples of COVID effects. As every aspects of the world have been affected, learning is the
most affected aspect because of the lock down announced by the governments and the shift to the distance learning or what it is called e-Learning. Hence, the stress has been supported and being rich. In this review, the effects of stress have been placed on highlight based on the modalities used to measure and analyze stress. The review methodology was to collect articles studying the effects of stress on learning and memory retrieval using Google scholar. The researchers of those articles were using a variety of methodology and measures to study the effects of stress. Twenty articles used the behavioral analysis model such as surveys, questionnaires, interviews, and stress scales. Whereas the literature reviewed seven paper studying stress influences on learning and memory based on Electroencephalogram (EEG). MRI (magnetic resonance imaging) is also a model used to determine the level of stress with four papers. Another four articles were selected to study the effects of stress with testing the level of cortisol hormones in the body and salivary cortisol. Finally, seven researchers used more the one model from the modality mentioned above.

**LITERATURE REVIEW**

This paper reviews different work literature related to the impact of academic stress on the memory and learning cognitive skills. For each work, the year of publication, the modality used, the methodology applied and the significant results of the work. Noticeably, it is clear that stress has an impact on learning and retrieval of probabilistic knowledge and sequence learning but it is not the case with procedural learning. Stress level also varies according to the subject being learnt and the environment of learning. Gender, exam phobia, requirements, mental health, change of lifestyle, quality of sleep, the field of studying weather theoretical or clinical, language barriers and more are factors that influence the level of stress.

**MAGNETIC RESONANCE IMAGING (MRI)**

Magnetic resonance imaging (MRI) is a method using powerful magnets radio waves and computer to take images of the parts of the body and how healthy they are. When it is used to scan the brain, MRI provides detailed pictures of the brain and produces a map of blood vessels that indicates the level of stress. It is used to study the changes of activity of the brain after and before the participants face stressor. The data are analyzed by studying and analyzing the images from the machine using behavioral and physiological changes of the brain. Table 1 summarizes the literature of the effects of stress on learning and memory based on MRI.

**ELECTROENCEPHALOGRAPHY (EEG)**

Electroencephalography (EEG) is an electrophysiological method used for monitoring the electrical activity of the brain. It is noninvasive placed on the scalp to detect the electrodes. It measures the voltage functions produced by the neurons of the brain. It is used to record the brain spontaneous electrical activities within a period of time.

<table>
<thead>
<tr>
<th>Paper</th>
<th>Year</th>
<th>Modality</th>
<th>Methodology</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>[19]</td>
<td>2020</td>
<td>MRI</td>
<td>Behavioral and physiological analysis</td>
<td>Cortisol has an effect on modifying memory tasks while retrieval. Stress obliges multi memory tasks to use normal memory that may reduce working memory.</td>
</tr>
<tr>
<td>[20]</td>
<td>2020</td>
<td>MRI</td>
<td>Statistical analysis, behavioral and physiological data analysis</td>
<td>Stress could affect the memory tasks such as retrieval that is to mean it support habitual tasks by cortisol level.</td>
</tr>
<tr>
<td>[21]</td>
<td>2019</td>
<td>MRI</td>
<td>Data analysis</td>
<td>The ability to memorize is affected by acute stress. Stress has impact on recalling memories from the past.</td>
</tr>
<tr>
<td>[22]</td>
<td>2017</td>
<td>Functional MRI</td>
<td>Data Analysis (image analysis)</td>
<td>Academic stress may affect the brain activities that may lead to change in the amount in food intake.</td>
</tr>
</tbody>
</table>

**Table 2: The Literature of the Effects of Stress on Learning and Memory Based on EEG**

<table>
<thead>
<tr>
<th>Paper</th>
<th>Year</th>
<th>Modality</th>
<th>Methodology</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>[24]</td>
<td>2020</td>
<td>EEG</td>
<td>Behavioral performances analysis, event-related potentials (ERPs), correlation analysis revealed</td>
<td>Enhanced working memory for high responders. There is a positive relationship between cortisol level and working memory.</td>
</tr>
<tr>
<td>[26]</td>
<td>2020</td>
<td>EEG</td>
<td>Naive Bayes, support vector, KNN (k-Nearest Neighbors), and random forest</td>
<td>Stress level is higher during first time task in the audience situation while it is less in the second time despite of the existence of audience</td>
</tr>
</tbody>
</table>

[23]. Here, the papers used EEG to gather data and information about participants before and after they introduced to stressors. Then, the data were analyzed to gather and notice the changes. Table 2 summarizes the literature of the effects of stress on learning and memory based on EEG.
The elderly inability to retrieve memory and maintain new knowledge is results from the stress faced during life. Thus, stress has a long-term effect on the health of cognitive functions.

Long term stress influences task of initializing the working memory and has an impact on attention.

The theta main power is enhanced by pre learning stress. Thus, the long-term memory retrieval could be improved by pre learning stress.

Table 3 summarizes the literature of the effects of stress on learning and memory based on cortisol level.

<table>
<thead>
<tr>
<th>Paper</th>
<th>Year</th>
<th>Modality</th>
<th>Methodology</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>[33]</td>
<td>2020</td>
<td>salivary cortisol level,</td>
<td>Statistical analysis questionnaire-based rating</td>
<td>Stress has an influence on learning and retrieval of probabilistic knowledge and null on sequence learning. Stress may support procedural learning but confuse explicit process.</td>
</tr>
<tr>
<td>[34]</td>
<td>2019</td>
<td>salivary cortisol level</td>
<td>Analysis of salivary cortisol socially evaluated cold pressor test -SECPT</td>
<td>Stress support memory if the stressors occur in the same context of the engaged memory.</td>
</tr>
<tr>
<td>[35]</td>
<td>2018</td>
<td>salivary cortisol level, socially evaluated cold-pressor test</td>
<td>Statistical analyses</td>
<td>The effect of stress on memory retrieval depends on the learning material, increases in stimuli material and decreases in ecological materials.</td>
</tr>
</tbody>
</table>

Table 4: the literature of the effects of stress on learning and memory based on Behavioral Analysis.

<table>
<thead>
<tr>
<th>Paper</th>
<th>Year</th>
<th>Modality</th>
<th>Methodology</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>[40]</td>
<td>2019</td>
<td>Perceived Stress Scale (PSS)</td>
<td>Machine Learning Algorithms</td>
<td>Stress could be detected by PSS before the exam. Thus, learner can be supported to reduce stress.</td>
</tr>
<tr>
<td>[41]</td>
<td>2018</td>
<td>Patient Health Questionnaire-9 PHQ-9 State-Trait Anxiety Inventory STAI Snaith Hamilton Pleasure Scale SHAPS</td>
<td>Task data analysis</td>
<td>Stress may worsen depression if it accompanies decision making.</td>
</tr>
<tr>
<td>Reference</td>
<td>Year</td>
<td>Methodology</td>
<td>Data Analysis</td>
<td>Findings</td>
</tr>
<tr>
<td>-----------</td>
<td>--------</td>
<td>----------------------</td>
<td>--------------------------------</td>
<td>--------------------------------------------------------------------------</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Functioning</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Questionnaire (NWFQ),</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>and the Demand-</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Control-Support</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>questionnaire (DCS),</td>
<td></td>
<td></td>
</tr>
<tr>
<td>[43]</td>
<td>2018</td>
<td>survey</td>
<td>Statistical Analysis</td>
<td>Stress arises from the feeling of insecurity and it will be less in save situations</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Scale of academic stress (SAS)</td>
<td></td>
</tr>
<tr>
<td>[46]</td>
<td>2018</td>
<td>interview-based study</td>
<td>Content Analysis Method approach</td>
<td>Learning environment has a vital role in the level of stress e.g., communication, learning tasks, context, and clinical scenario</td>
</tr>
<tr>
<td>[47]</td>
<td>2018</td>
<td>Survey California Psychological Inventory</td>
<td>Data analysis</td>
<td>Learning environment has a vital role in the level of stress, student indecency reduces stress.</td>
</tr>
<tr>
<td>[49]</td>
<td>2018</td>
<td>survey</td>
<td>The first was The Perception of Academic Stress Scale (PAS) The Self-Regulatory Inventory Mindful Attention Awareness Scale (MAAS),</td>
<td>Stress affects negatively self-regulation. Stress restricts some learning skills such as critical thinking and problem solving. Mindfulness is also influenced by stress.</td>
</tr>
<tr>
<td>[50]</td>
<td>2018</td>
<td>questionnaire</td>
<td>Academic Stress Scale Data analysis</td>
<td>Stress level varies according to the subject being studied and gender.</td>
</tr>
<tr>
<td>[51]</td>
<td>2017</td>
<td>survey</td>
<td>Perceived Stress Scale (PSS) Data analysis</td>
<td>Stress level varies according to the subject being studied. Stress level reduces with experience during studying journey. Caffeine is being used to treat stress as a drug.</td>
</tr>
<tr>
<td>[52]</td>
<td>2017</td>
<td>survey</td>
<td>Positive Mental Health Scale With Educational Stress Scale for Adolescents</td>
<td>Private schools’ students experience high level of stress while governmental schools are less, the same result for mental health. Stress also has an impact the mental health of students.</td>
</tr>
<tr>
<td>[53]</td>
<td>2017</td>
<td>questionnaire</td>
<td>Data analysis</td>
<td>Female students experience stress more than male students. Educational level also affects the level of stress.</td>
</tr>
<tr>
<td>[54]</td>
<td>2016</td>
<td>Cross-sectional survey</td>
<td>Data Analysis-Levene statistic</td>
<td>Academic stress and cell phone addiction doesn’t affect their studying. If academic stress rises cell phone addiction rises and vice versa. These findings are stronger with male than female</td>
</tr>
<tr>
<td>[55]</td>
<td>2016</td>
<td>questionnaire</td>
<td>(ANOVA) ANalysis Of Variance</td>
<td>Stress has no effects on students’ sleep time but effect the sleeping quality. Students with low academic achievement may suffer with sleep problems which may worsen academic stress.</td>
</tr>
<tr>
<td>[56]</td>
<td>2016</td>
<td>The PSS-14 and the</td>
<td>Statistical Package</td>
<td>Stress level varies according to the subject being studied.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Learining and Memory under Stress: A Review Study with Evaluation Techniques

Stress Survey for the Social Sciences (SPSS) being studied and the exams are the strongest stressor. Number of children for married students increases stress. Full time track students experience more stress.

Goldberg's General Health Questionnaire (GHQ-28) Male students are more stressful and depressed than female. Language obstacle may worsen the stress with students. New enrolled students are facing stress more than seniors.

Ways of Coping Inventory (WCI) Studying for the exam is the strongest stressor for theoretical subjects. Clinical practice stressor order as: instructor criticism, facing dying patient and fear of making errors.

Table 5: the literature of the effects of stress on learning and memory based on multiple models.

<table>
<thead>
<tr>
<th>Paper</th>
<th>Year</th>
<th>Modality</th>
<th>Methodology</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>[57]</td>
<td>2016</td>
<td>Electroencephalogram (EEG), cortisol level Questionnaire Transcranial direct current stimulation (tDCS) State-Trait Anxiety Inventory (STAI)</td>
<td>There is a vital correlation between the dorsolateral prefrontal cortex (dLPFC) and stress manipulating. Social stress has an impact on the working memory.</td>
<td></td>
</tr>
<tr>
<td>[58]</td>
<td>2016</td>
<td>Electroencephalogram (EEG) Functional near-infrared spectroscopy (fNIRS) Statistical Analyses</td>
<td>Brain activities are lower in stressed situations. FMRI is more accurate than EEG</td>
<td></td>
</tr>
<tr>
<td>[60]</td>
<td>2018</td>
<td>salivary cortisol Vital signs Questionnaire. Data analysis</td>
<td>Stress can support the instruction of learning and this depends on the physiological stress response. Whereas anxiety reduces the learning performance.</td>
<td></td>
</tr>
<tr>
<td>[61]</td>
<td>2020</td>
<td>MAST galvanic skin response (GSR) measures. Self-Report Questionnaire, analysis of variance (ANOVA)</td>
<td>Stress doesn’t have negative impact in all hippocampal-based learning types. “declarative based memory”</td>
<td></td>
</tr>
<tr>
<td>[63]</td>
<td>2017</td>
<td>salivary cortisol Heart rate Data analysis</td>
<td>Habit learning is impaired by psychological stress rather than reinforced.</td>
<td></td>
</tr>
</tbody>
</table>

FUNCTIONAL NEAR-INFRARED SPECTROSCOPY (FNIRS)

Table 5 shows the effect of stress on learning and memory based on multiple modalities. The researchers used models mentioned above to study the effect of stress on memory and learning and how the used modalities vary in their accuracy and results.

Functional near-infrared spectroscopy (fNIRS) is used to notice the simultaneous changes in the prosperities of the cortex of human brain from different places of the scalp. It displays the results by picturing or mapping the needed area. Recently, this technology has been used to detect the effects of stress on cognitive functions. Searching Google Scholar, fNIRS was not found as a single modality to study the effects of stress on learning and memory. The literature will include this modality while reviewing compound modality section.

DISCUSSION

In this review, it is clear that stress has an impact on the working memory, and as a result it influences the learning process. Cortisol is the responsible hormone for controlling stress. From nerves system point of view, stress and the increase of cortisol hormone were accompanied by a high level of activity in the dorsal striatum while memorizing task. But stress doesn’t function negatively in all learning situation, it depends on the learning context or the learning task itself. Stress that is found within the context of a person well-known field or his own experience will increase the attention and enhance the working memory during the process of

1606 Systematic Reviews in Pharmacy Vol 12, Issue 1, January 2021
memory retrieval, but this will not happen with irrelevant experience [69]. Stress level also varies according to the subject being learnt and the environment of learning. Gender, exam phobia, requirements, mental health, change of lifestyle, quality of sleep, the field of studying weather theoretical or clinical, language barriers and more are factors that influence the level of stress. In contrast some researchers’ findings reported that stress does not have impacts in some learning processes and memory performance. Thus, stress can be manipulating in a way to support learning and memory retrieval. Stress has an impact on learning and retrieval of probabilistic knowledge and sequence learning but it is not the case with procedural learning [37]. Importantly, social learning has no relationship with stress level; it is caused from the behaviors of learners themselves [36]. Undoubtedly, stress could be beneficial to learning and memory if the causes of stress occur in the same context of the task being practiced [34]. Remarkably, there are many factors that reduce stress or enhance working memory: social supports, feeling of security, motivation, along with experience, caffeine intake, and control over phone addiction, mental health and academic achievement.

**CHALLENGES AND FUTURE TRENDS**

Studying stress and its effects on the learning and memory performance is a wide subject. Undoubtedly, stress has three types: acute stress, episodic acute stress, and chronic stress and each one has its symptoms and characteristics. Stress also falls in many branches such as academic stress, social stress, environmental stress cultural stress and more. Thus, stress could be studied from different point of view. This section summarizes some of the challenges and future works that could be investigated:

- The mental health and the changes lifestyle and their relationship with the academic stress and academic achievement [70].
- Gender differences and their correlation in the level of stress among students.
- Does second language affect the level of stress as a media of instruction [71].
- The psychological aspect of stress among students and the family support.
- It is recommended to develop a methodology to study stress effects on learning and memory performance [17].
- The role of instructors and teacher of manipulating stress and reducing stress [72]
- Social factors may be further study stress and memory such media addiction [54]
- Parents’ role in manipulating stress and determining the level of stress [73]
- Advanced technologies such as Internet of Things (IoT), wearable computing, big data, cloud and fog computing have to be investigated more to enhance evaluation capabilities [74-77]

**CONCLUSION**

Lately, the curfew and the lock down announced by governments and health organizations because of the pandemic of Covid-19 charged students with new stressors. However, the authors aimed to address the following question “how does the stress affect students’ achievement to give chance for those who are interested in solving students’ difficulties to provide solutions?” In this paper, six evaluation techniques about the effects of stress on memory and learning cognitive functions (such as, fNIRS, EEG, MRI, ECG, behavioral analysis and multiple models) are reviewed. Moreover, results of each study which is reviewed in the literature are discussed and highlighted. Finally, the challenges and possible future directions are highlighted.

**REFERENCES**


45. Heo, JeongChul, and Sumi Han. "Effects of motivation, academic stress and age in predicting self-directed


73. A. Arun, R. Garg, and B. S. Chavan. "Stress and suicidal ideation among adolescents having


