Psychology, 2022, 13, 1685-1696
https://www.scirp.org/journal/psych
ISSN Online: 2152-7199
ISSN Print: 2152-7180

Investigating the Effects of Stressful Stimuli on Learning and Working Memory

William Liu

West Windsor Plainsboro High School South, Mercer County, NJ, USA
Email: williampianist@gmail.com

How to cite this paper: Liu, W. (2022). Investigating the Effects of Stressful Stimuli on Learning and Working Memory. *Psychology, 13*, 1685-1696.
https://doi.org/10.4236/psych.2022.1312105

Received: September 3, 2022
Accepted: November 4, 2022
Published: November 7, 2022

Abstract

Emotional stress in the form of fear, tension, or nervousness is ubiquitous to daily life. Studies have been conducted to determine their effects on a wide range of animals' memory, showing an improvement to memory recall under moderate stress while high stress impaired both memory formation and recall. This paper discusses the previous research done on this topic and the significance of their results, along with important figures for comprehension. 3 studies were examined and other background information was researched surrounding the topic of psychology, corticosteroids associated with stress, and the role of the hippocampus and amygdala in memory. The paper argues that an improved memory under stress evolved to better suit the needs of primitive animals, while excessively stressful events are blocked out for protection. The paper is meant to illuminate the potential purpose of stress and its effects on memory and concludes with applications in the real world and future.

Keywords

Stress, Memory, Learning, Classical Conditioning, Operant Conditioning, Habituation, Sensitization, Fear

1. Introduction

Psychological stress has both positive and negative effects on memory and learning in different circumstances. Stress releases corticosteroids which affect the hippocampus, a key organ in memory formation. Chronic stress can severely impede memory as a result of this harmful long-term effect on the hippocampus. (Scott, 2021) However, stress does not always impede memory, as studies show that fear and trauma heavily impact the way the brain remembers events, deeply imprinting stressful memories (Vogel & Schwabe, 2016). Traumatic memories have been proven to be more vivid, long-lasting, and hard to modify, although other studies have shown that fearful memories may also be blocked out completely afterward as a defense mechanism (Abercrombie et al., 2006). In the brain, fear and traumatic experiences activate the amygdala, two almond-shaped masses of gray matter on each side of the brain, which is integral to remembering emotions such as fear (Cushman & Byrne, 2017). This system of having an intense and vivid recollection of traumatic events evolved to protect humans from threats, as remembering a stressful event can help in avoiding dangerous stimuli. However, the way the brain works has also been shown to be fluid and changeable, a concept is known as brain plasticity (Puderbaugh & Emmady, 2022). The brain can physically reorganize its structure and connections in response to stimuli, leading to some stressful memories being completely changed or inaccurate. The brain does this in response to experiences that necessitate adaptation, or if the brain is injured and needs to move the function of one area to another (Puderbaugh & Emmady, 2022). Deeply imprinted memories of fear and brain plasticity are two contrasting concepts, as traumatic recollections are not easily changed though the brain is known to be very adaptable. As such, it is in this paper that the effect of fear on brain plasticity is tested.

This topic was chosen due to its relevance in both survival of primitive organisms as well as learning and memory in the workplace or school. In stressful situations such as a job interview or important exam, the effects of the aforementioned stress could be extremely important for the results and progress of the student or interviewee. Depending on the positive or negative effects of stress, institutions could reduce stress to provide a better memory recall environment and utilize the positive effects of stress and emotional arousal in certain situations. The results of these studies may also provide valuable insight into survivalistic instincts in the animal brain. Memory formation during stressful situations is likely essential for survival against the multitude of threats in nature, such as predators. Though the workings of the brain are extremely complex, this correlation between stress and memory can be studied and applied to biology and the real world.

One study tested stress and its effect on the hypothalamus, which in turn affects corticotropin-releasing factor and arginine vasopressin hormone (Ness & Calabrese, 2016). The stress tested in this study was inescapable and unpredictable stress to simulate stress found in daily lives. Stress generally impairs hippocampal-dependent memory tasks. The hippocampus is highly involved in forming declarative/explicit memories. The main concept being studied in this paper was the correlation between corticosteroids and stress. The results showed that transient stress levels had a beneficial effect on hippocampal activity but extended periods of intense stress lead to harmful effects. This was highly tied to Hans Selye's theory (Jackson, 2014) that stressors produce physiological reactions (known as the alarm reaction stage) resulting in an adaptive stage allowing body chemicals to fight off external threats. Once the chemicals are depleted, the body enters an exhaustion stage. Overall, this was known as "general adaptation syndrome." (Kim et al., 2015)

Another study showed that the amygdala had a fundamental role in mediating stress reactions (Roozendaal et al., 2009). Neurons located in the nucleus of the hypothalamus synthesize and release a corticotropin-releasing hormone which triggers the release of adrenocorticotropic hormone (ACTH) from the pituitary gland into the bloodstream. ACTH affects the adrenal glands and begins the release of glucocorticoids from the adrenal cortices. Glucocorticoids alter the function of multiple body tissues in order to mobilize or store energy to meet the demands of a stress challenge (Brennan, 1) (Roland, 2022). Emotionally significant events are well-remembered and the amygdala plays a big role in this phenomenon (Wright, 2020). Stress hormones and stress-activated neurotransmitters are also highly involved in this process. Another study showed that response bias memory was worse for negative items (Raffington et al., 2020). Girls tended to show memory suppression for negative information. Their memory is also more strongly modulated by stress and associated cortisol response. A higher cortisol stress response was associated with better emotional memory in girls in the stress condition, but memory was not associated with cortisol secretion in boys.

2. Methods

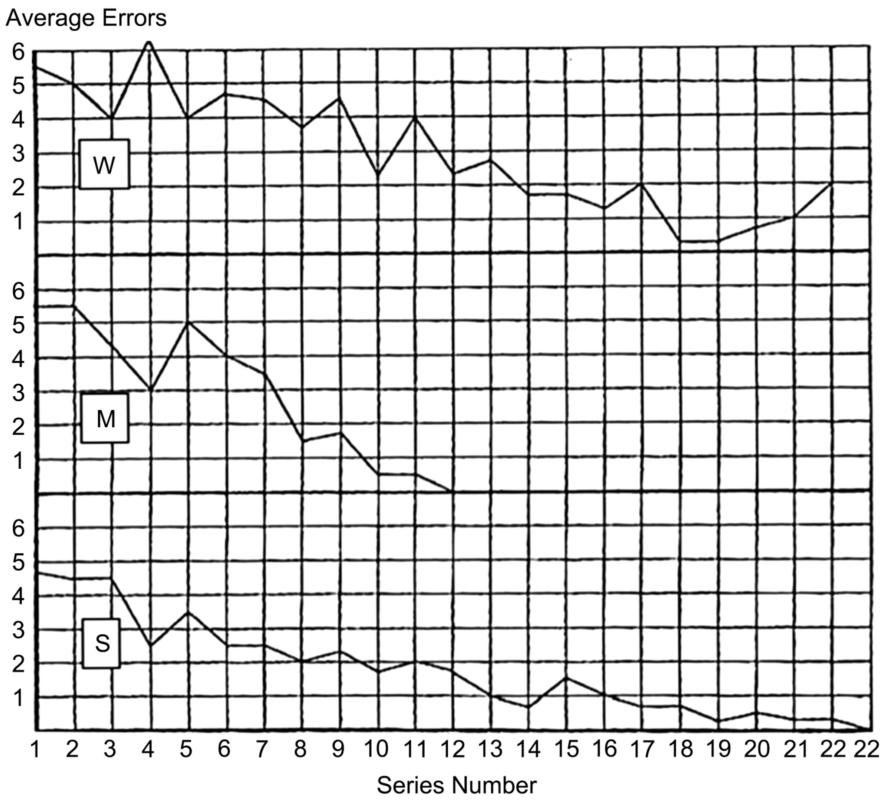
Data Collection: Past experiments and reports relevant to the topic were identified from scientific or medical databases. Databases included the National Library of Medicine, the National Center for Biotechnology Information, Google Scholar, and ScienceDirect. The results were searched for included any experiment related to psychological stress and its physiological effects on memory or brain function in a substantial way. Keywords included fear, stress, and their effects on memory and learning. "Effects of fear on memory" was searched in these search engines. The three papers analyzed were *Effects of stress on 6-to-7-year-old children's emotional memory differs by gender* (Raffington et al., 2020), *Stress Effects on Working Memory, Explicit Memory, and Implicit Memory for Neutral and Emotional Stimuli in Healthy Men* (Luethi et al., 2008), and The Relation of Strengths of Stimulus to Rapidity of Habit Formation (Yerkes & Dodson, 2009).

Data was usually gathered with human children or small mammals, with memory being tested through either learned behaviors, cortisol level, brain neuroimaging, or memory retrieval testing. Most studies have shown that stress impairs memory and in relation to hippocampal function. The hippocampus is most involved in long-term memory while the amygdala assigns emotion to the memory, leading to memories that are more permanent and easily accessed. (Fogwe et al., 2021) However, when a person is stressed or experiencing negative emotions at the moment, it has been shown that memory retrieval is hindered (Cushman & Byrne, 2017). Cortisol, commonly known as the stress hormone, is correlated with the function of the hippocampus and memory due to the hindered cognitive function and memory formation associated with high cortisol levels (Mayo Clinic Staff, n.d.). The results of each experiment were compared and corroborated.

3. Results

It has been proven that high levels of psychological stress impede memory recollection in organisms at the moment but help establish new ones by associating a strong emotional response with the memory that is formed. One study done in the past measured learning in rodents when under psychological stress caused by a painful shock (Yerkes & Dodson, 2009). It was intended to discover whether the strength of the stress caused by a stimulus affected how quickly a mouse learned a habit and what strength would facilitate the maximum speed for learning. Mice were given the option between two doors, one black, and one white, and if they ever chose the black door and entered the black box they would be shocked. This was known as the "discrimination box." The wooden box was 94 cm long, 30 cm wide, 11.5 cm deep, and was divided into 3 parts: A nest box, an entrance chamber, black and white electric boxes, and swinging doors back from the nest to the alley. The floors of each box would have not circuited wires which would become circuited upon a mouse's foot touching two adjacent wires. Each mouse undergoes ten tests. The orientation of the black and white boxes (whether they are on the right or left) is random in each trial. However, the color and orientation of the boxes are never the same for more than 4 trials. To encourage the mouse to enter one of the boxes, an experimenter would insert a cardboard piece and move it, restricting the movement of the mouse, and pushing it such that eventually the mouse would be forced to enter one of the rooms. 40 mice were tested and were only allowed to return to the nest room upon entering the white box. Each mouse would undergo a test with a partner of the opposite gender, and a mouse that could identify the correct box to enter on the first attempt for 3 consecutive days was considered to have formed the habit and was subsequently removed from the experiment. There were 3 strengths of stimulus, weak, medium and strong, each corresponding to a different voltage. There were also 3 sets of experiments done, set 1 had intermediate visually different boxes, set 2 had greatly varied, and 3 had very slightly varied. For set 1, tests with weak stimuli (small shocks) were done for 20 days and only one of the four individuals tested developed a perfect habit of choosing the white box. The number of errors made by each of the 4 mice generally decreased as the tests went on, but on the 18th day, only one of the mice had developed a habit, while the 3 others had failed for all 20 days. On the other hand, mice undergoing a medium stimulus showed much greater learning skills. By the 12th trial, all 6 mice had successfully developed the habit of choosing the white box. However, the strong stimulus showed results similar to the weak stimulus, in that habit formation took many trials. While all 6 mice formed the habit after 23 trials, the first one was only formed after 16 trials. This indicated that a medium stimulus would result in the best conditions for learning, with small and high stimuli being more difficult. The results from test 2 actually contradicted the results from test 1, as the stronger stimuli resulted in quicker learning even at the strongest shock levels. Most mice developed the habit after 18 trials in the tests with the lowest voltage compared with only 8 trials in the tests with the highest voltages. This indicated that higher stimuli generally resulted in quicker habit formation, despite any potentially harmful effects from the arousing stimuli. The results of set 3 were similar to set 1, in that a medium stimulus resulted in the quickest learning while a minimal or excessive stimulus resulted in hindered habit-forming. However, the mice subjected to high voltage shocks were less careful and deliberate with their decisions.

From **Figure 1**, this graph depicts the errors made by mice, which each consisted of ten trials. W (top) shows weak stimulus, M (middle) shows medium stimulus, and S (bottom) shows strong—Average errors made were in the y axis while the amount of days needed were the x axis. Weak and strong resulted in the mice taking much longer to learn than the medium stimulus (Adapted from Yerkes & Dodson, 2009).



Curves of learning. Ordinates represent series of ten tests each, and abscissae represent the average number of errors for four mice in each series. W designates the error curve for the individuals which were trained under the condition of weak electrical stimulation; M, designates the corresponding curve for the medium strength of the stimulation; and S, that for the strong stimulus.

Figure 1. Average number of errors for 4 mice throughout each series.

From Figure 2, the system activates in response to stressful events. In a stressful encounter, the autonomic nervous system is activated within seconds and releases catecholamines (such as norepinephrine) from the adrenal medulla and the locus coeruleus of the brainstem. Catecholamines are involved in the fight-or-flight response, but they also have a significant impact on attention, working memory, and long-term memory. Somewhat slowly, the hypothalamic-pituitary-adrenal axis is activated, corticotropin-releasing hormone (CRH) is released from the hypothalamus, and the anterior pituitary is stimulated to secrete adrenocorticotropic hormone (ACTH). ACTH then causes the adrenal cortex to produce cortisol and release it into the bloodstream. Cortisol reaches peak levels approximately 20 to 30 minutes after stress develops and quickly enters the brain, affecting cognition and behavior. Cortisol feedback to the pituitary gland, hypothalamus, and other brain regions (such as the hippocampus) prevents the system from being disabled.

From Figure 3, a depicts a timeline of stress/control conditions and memory tasks. B depicts examples of high negative stimuli (monster), low negative stimuli (ashtray), neutral (fish), low positive stimuli (lollipop), and high positive (money) items placed on neutral backgrounds.

From Figure 4, long-term dysregulation of norepinephrine and Cortisol systems, and vulnerable areas of hippocampus, amygdala, and medial prefrontal cortex that are affected by trauma. GC = glucocorticoid, CRF = corticotropin-releasing factor, ACTH = adrenocorticotropin hormone, NE = norepinephrine, HR = heart rate, BP = blood pressure, DA = dopamine, BZ = benzodiazapine, GC = glucocorticoid

Overall, medium stimuli showed the best results and had the fewest average errors and the quickest habit formation. This indicated that a stimulus that is both memorable and noticeable as well as not too traumatic is the best for forming habits and memories. How different the two boxes were in color also played a major role in habit formation, as more distinct colored boxes allowed for easier habit development. Of course, how easily something is remembered

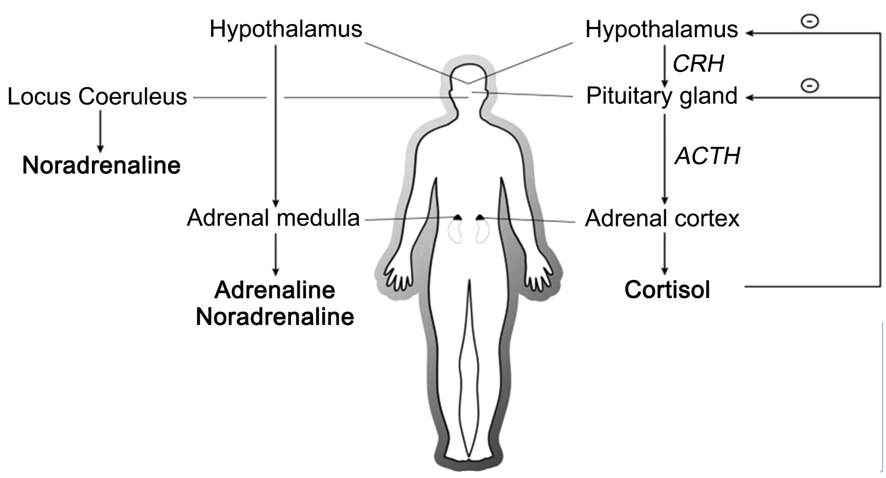


Figure 2. Systems activated in response to stress.

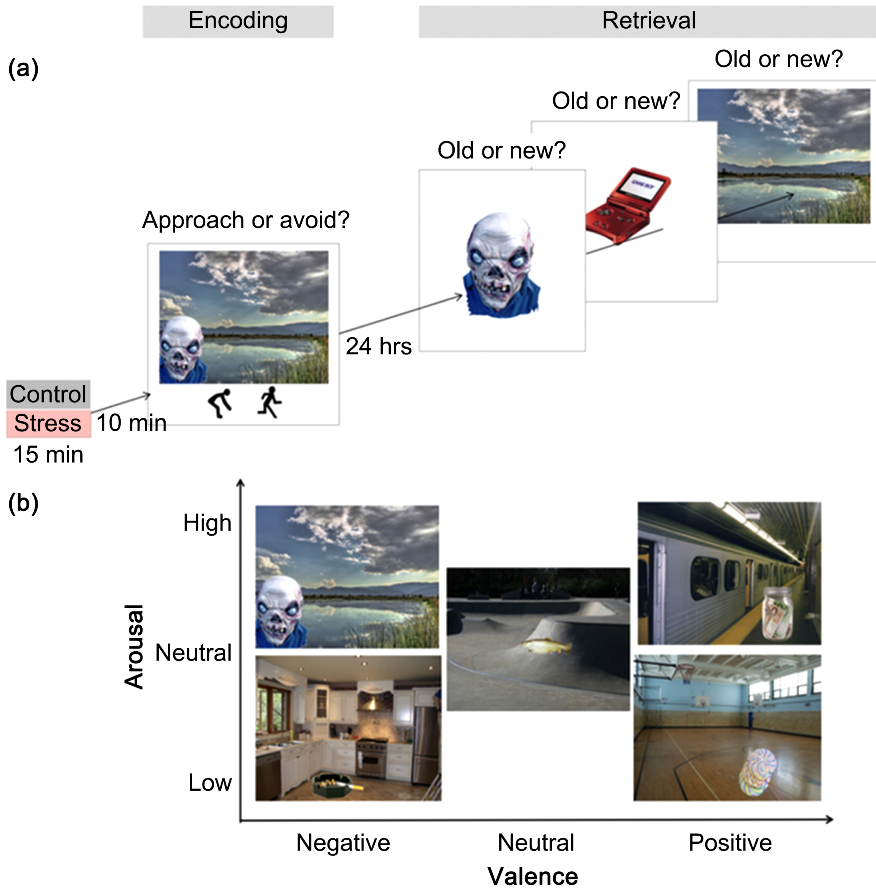


Figure 3. Testing children's responses to stressful, neutral, and positive stimuli.

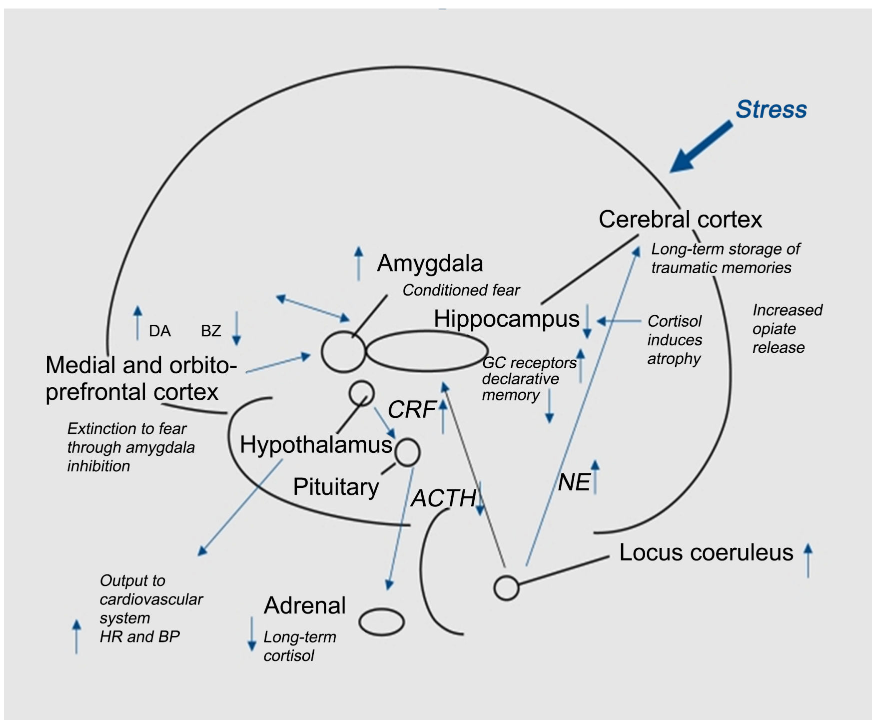


Figure 4. Cortisol systems and their effect on memory storage structures.

also plays an important role in forming habits or memories. However, this study only tested rodents, which are genetically convenient and physiologically similar to humans, but most likely exhibit different behaviors (Bryda, 2013). In this case, the stress was caused by the electrical shocks, and the memory was shown through habit development.

A different study measured the physiological effects of stress caused by the body's natural response to stress. These studies were done based on Hans Selye's report (Jackson, 2014) that stressors produced common physiological effects, such as adrenal gland enlargement or secretions, which eventually exhaust the body. That hypothesis may have been inaccurated, however, as the scientists in this study believed that the harmful effects on the body were actually caused by sustained high neuroendocrine activity rather than the depletion of stress hormones and immune function. Stress reactions are also closely correlated to hippocampal function because of the high amount of receptors for corticosteroids in the hippocampus (cortisol in humans) and thus it is susceptible to corticosteroid action (Roland, 2022). Some studies mentioned in their report that organisms exposed to unavoidable stressors had impaired learning and escape-avoidance responses, due to the helpless nature of their actions (*Learned Helplessness*, n.d.). The majority of other studies have reported that exposures to stress or high levels of corticosteroids impair the performance of memory tasks that are dependent on the hippocampus. This has been studied in rats as well as humans. Long-term potentiation, the process by which synapses are strengthened resulting in a more robust nervous response (Gruol, n.d.), is hindered by stress and high cortisol levels (Jovanovic et al., 2010). It was hypothesized that feelings of stress or helplessness saturate the hippocampal synapses, causing a decrease in synaptic strength for long-term potentiation and memory retention (Pittenger & Duman, 2007). An alternate model argues that stress causes synaptic plasticity to favor long-term depression over long-term potentiation, effectively reducing neuron effectiveness in a certain pathway (Pittenger & Duman, 2007). Traumatic stress has also been known to cause morphological changes in the hippocampus (Bremner, 2006). PTSD patients have smaller hippocampal volumes, which causes deficits in verbal memory. Stress can cause many structural changes to the hippocampus, corresponding with worsened spatial navigation and episodic memory (memories of personal events and details). Intrahippocampal infusion of corticosteroids caused PTSD-like memory impairment (Bentz et al., 2013). However, high corticosteroid levels do not always mean high levels of stress, and lowering corticosteroids during stress or raising it in calm situations could lower or cause stress effects, respectively.

High corticosteroid levels caused by environmental stimulation, for example, do not impair memory (Roland, 2022). The amygdala enhances glucocorticoid secretion in response to stress and also changes during high levels of stress (Roland, 2022). Amygdala lesions prevent stress responses in the body and behavior, such as gastric erosions, and can block the effects of stress on hippocampal LTP and spatial memory, despite any increases in corticosteroid levels (Wright, 2020). These experiments were only done on rats, however. Stress affects many components of the body and is most likely not just changes in neurochemical levels.

Another study was done to test the effect of showing positive, neutral, and negative stimuli to young children and determining how memory formation was impacted (Raffington et al., 2020). Positive stimuli included a jar of money and lollipops, the neutral stimulus was a fish, and the negative stimulus was a clown-like monster and a cigarette. Following a period of 24 hours, the children tested were asked to identify if they had seen the stimuli provided before. The stimuli were also presented on a neutral background to avoid skewed results. Children reported their feelings by pointing to comic faces indicating 0 is happy, 1 is neutral, and 2 is upset. Saliva samples were also taken for assessment of cortisol concentrations, stored at −80 degrees celsius for preservation and analyzed after centrifugation through enzyme immunoassay. Calculations were done to correlate cortisol response to stress and control variables and the mean cortisol response slope indicated the average change in cortisol per 10 minutes. The procedure for testing the children was as follows: Children were shown a fixation cross for 1 second, the stimulus and background for 3 seconds, and were then asked whether they would approach or avoid the stimulus within 4 seconds. The following day, they saw 250 items and backgrounds in a random order, half of which were previously seen while half were new. They were asked to indicate whether each item was new or old. This was the stress test—there was also a control task that was assigned to fewer children. Naturally, negative stimuli were approached significantly less than neutral and positive stimuli. Positive stimuli were also approached significantly more than neutral stimuli. Results showed that girls avoided negative items and approached positive items more than boys, though this may have been a result because of gender differences and item preferences. Girls also reported higher subjective stress and higher cortisol stress responses. Items that were highly arousing vs low arousing were also differentiated by girls, but not by boys. 73.88% of children identified previously seen items correctly and 15.9% of new items were inaccurately identified as old. Results showed that low arousing negative items were remembered less than usual in boys, and amplified in girls. Negative items in general were remembered less. Girls also had better emotional memory for highly positive stimuli but not low. As such, higher cortisol responses were related to better memory for girls in response to highly positive and slightly negative stimuli, while it was unrelated to boys' memory. It was hypothesized that the amygdala interacts with the hippocampus to increase arousal for remembering experiences, which was seen in this experiment. Highly arousing stimuli, positive or negative, generally resulted in better memory, but some negative stimuli that were not highly arousing actually hindered memory. From this, it was suspected that young children, especially girls, may attempt to block out negative memories. The lack of memory for low arousing negative content may have been because those memories were easier to process and regulate.

4. Conclusion

Overall, it is clear that stress and the resulting emotional response play a large role in memory in a variety of ways. In the first experiment mentioned, associating stress with learning helped rats form a habit of choosing the correct box to enter. The painful shock served as the stress inducer and increasing its intensity generally increased the speed at which test subjects developed the habit. However, it is also important to note that increasing the pain caused by the shock also hindered learning after crossing a certain threshold—from this, it can be guessed that stress improves memory and habit formation, but excessive, traumatizing stress does the opposite, hinders learning and potentially blocks out the memory of the moment. This was supported in the experiment where children were tested to determine the effects of stress (measured in cortisol levels, a good indicator of stress) on memorization of positive, neutral, and negative stimuli. The results reported that arousing stimuli, positive or negative, were generally remembered better than neutral stimuli. However, highly negative stimuli were reported to be remembered less in girls, indicative of the desire to avoid stressful memories and the potential blocking out of memories. In the other study, it was revealed that stress response is highly connected with the amygdala and can have large effects on the hippocampus, a brain structure highly involved in memory formation. Stress may saturate hippocampal synapses and prevent long term potentiation as well as memory formation—hippocampal deformation also impairs memory in neurological diseases. The evolutionary advantage would likely explain the correlation between stress and memory—in nature, stressful situations would be remembered in order to avoid future similar dangers. However, this also contradicts stronger stressors which worsen memory. This could be explained through psychology as a defense mechanism against painful memories, though the biological advantage of this is unknown. In conclusion, the effect of stress on memory is notable and should be investigated further. In real world situations, stress should be utilized and minimized when needed. In schools, test-taking environments should be as calming as possible, to prevent the memory recall effects of stress. However, emotional arousal during class can also be utilized to form longer lasting memories. For example, an excitable and positive teacher who creates engaging and fun activities during class may prove to be much more efficient than traditional textbook learning. It is imperative to recognize both the positive and negative effects of stress on the brain and memory, and adapt to it in a way that maximizes efficiency and learning.

Acknowledgements

I thank Roger Lefort and Lynn Zuo for their support with this paper.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

References

Abercrombie, H. C., Speck, N. S., & Monticelli, R. M. (2006). Endogenous Cortisol Elevations Are Related to Memory Facilitation Only in Individuals Who Are Emotionally Aroused. *Psychoneuroendocrinology, 31,* 187-196. https://doi.org/10.1016/j.psyneuen.2005.06.008

Bentz, D., Michael, T., Wilhelm, F. H., Hartmann, F. R., Kunz, S., von Rohr, I. R., & de Quervain, D. J. (2013). Influence of Stress on Fear Memory Processes in an Aversive Differential Conditioning Paradigm in Humans. *Psychoneuroendocrinology*, *38*, 1186-1197. https://doi.org/10.1016/j.psyneuen.2012.12.018

Bremner, D. (2006). Traumatic Stress: Effects on the Brain. *Dialogues in Clinical Neuroscience, 8,* 445-461. https://doi.org/10.31887/DCNS.2006.8.4/jbremner https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3181836/

Bryda, E. C. (2013). The Mighty Mouse: The Impact of Rodents on Advances in Biomedical Research. *Missouri Medicine, 110,* 207-211. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3987984/

Cushman, S., & Byrne, J. H. (2017). Special Issue on the Effect of Fear and Stress on Memory. *Learning & Memory, 24,* 1.

Fogwe, L. A., Reddy, V., & Mesfin, F. B. (2021, July 22). Neuroanatomy, Hippocampus. In *StatPearls*. StatPearls Publishing. https://www.ncbi.nlm.nih.gov/books/NBK482171/

Gruol, D. L. (n.d.). Long-Term Potentiation. *Science Direct*. https://www.sciencedirect.com/topics/neuroscience/long-term-potentiation#:~:text=Long%2Dterm%20potentiation%20(LTP)%20is%20a%20process%20involving%20persistent,for%20the%20study%20of%20memory

Jackson, M. (2014). Evaluating the Role of Hans Selye in the Modern History of Stress. In D. Cantor &, E. Ramsden (Eds.), *Stress, Shock, and Adaptation in the Twentieth Century*. University of Rochester Press. https://www.ncbi.nlm.nih.gov/books/NBK349158/

Jovanovic, T., Norrholm, S. D., Blanding, N. Q., Phifer, J. E., Weiss, T., Davis, M. et al. (2010). Fear Potentiation Is Associated with Hypothalamic-Pituitary-Adrenal Axis Function in PTSD. *Psychoneuroendocrinology, 35,* 846-857. https://doi.org/10.1016/j.psyneuen.2009.11.009 https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2875386/

Kim, E. J., Pellman, B., & Kim, J. J. (2015). Stress Effects on the Hippocampus: A Critical Review. *Learning & Memory, 22*, 411-416. https://doi.org/10.1101/lm.037291.114

Learned Helplessness (n.d.). Science Direct. https://www.sciencedirect.com/topics/medicine-and-dentistry/learned-helplessness

Luethi, M., Meier, B., & Sandi, C. (2008). Stress Effects on Working Memory, Explicit Memory, and Implicit Memory for Neutral and Emotional Stimuli in Healthy Men. *Frontiers in Behavioral Neuroscience, 2,* Article No. 5. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2628592/

Mayo Clinic Staff (n.d.). *Chronic Stress Puts Your Health at Risk*. Mayo Clinic. https://www.mayoclinic.org/healthy-lifestyle/stress-management/in-depth/stress/art-20046037

Ness, D., & Calabrese, P. (2016). Stress Effects on Multiple Memory System Interactions. *Neural plasticity, 2016,* Article ID: 4932128. https://doi.org/10.1155/2016/4932128

Pittenger, C., & Duman, R. S. (2007, September 12). *Stress, Depression, and Neuroplasticity: A Convergence of Mechanisms*. *Nature, 33,* 88-109. https://doi.org/10.1038/sj.npp.1301574 https://www.nature.com/articles/1301574#:~:text=Correspondingly%2C%20stress%20enhances%20synaptic%20plasticity,fear%2C%20anxiety%2C%20and%20emotion

Puderbaugh, M., & Emmady, P. D. (2022, May 8). Neuroplasticity. In *StatPearls*, StatPearls Publishing. https://www.ncbi.nlm.nih.gov/books/NBK557811/

Raffington, L., Falck, J., Heim, C., Mather, M., & Shing, Y. L. (2020). Effects of Stress on 6- and 7-Year-Old Children's Emotional Memory Differs by Gender. *Journal of Experimental Child Psychology, 199,* Article ID: 104924. https://doi.org/10.1016/j.jecp.2020.104924

Roland, J. (2022, June 10). *Glucocorticoids: Uses, Types, Side Effects, and Risks*. WebMD. https://www.webmd.com/multiple-sclerosis/what-are-glucocorticoids

Roozendaal, B., McEwen, B. S., & Chattarji, S. (2009). Stress, Memory and the Amygdala. *Nature Reviews Neuroscience, 10,* 423-433. https://doi.org/10.1038/nrn2651

Scott, E. (2021, October 7). *How Stress Works with and Against Your Memory*. Verywell Mind. https://www.verywellmind.com/stress-and-your-memory-4158323

Vogel, S., & Schwabe, L. (2016) Learning and Memory under Stress: Implications for the Classroom. *NPJ Science Learn, 1,* Article No. 16011. https://doi.org/10.1038/npjscilearn.2016.11

Wright, A. (2020, October 10). *Limbic System: Amygdala (Section 4, Chapter 6) Neuroscience Online: An Electronic Textbook for the Neurosciences*. Department of Neurobiology and Anatomy, the University of Texas Medical School at Houston. https://nba.uth.tmc.edu/neuroscience/m/s4/chapter06.html

Yerkes, R. M., & Dodson, J. D. (2009, January 17). *Classics in the History of Psychology—Yerkes & Dodson (1908)*. LiU IDA. https://www.ida.liu.se/~769A09/Literature/Stress/Yerkes,%20Dodson_1908.pdf