Activation of the Human Sympathetic Nervous System: Effects on Memory Performance

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Key Points Summary
- The sympathetic nervous system is activated during a fear response.
- Physiological changes result from the sympathetic nervous system activation including increased heart rate, skin conductance and changes in brain wave activity.
- Changes in the body brought about by the sympathetic nervous system results in a decrease in memory performance, which could inhibit performance in a stressful situation such as an academic exam.
- The changes brought about by the sympathetic nervous system may be inconspicuous through non-invasive techniques such as EEG.
- Memory performance under stressful situations, such as eyewitness accounts of a violent crime, should be scrutinized, and academic exam results should be evaluated with these findings taken into consideration.
- Total words of summary: 114 words

Abstract
The fight-or-flight response activates the sympathetic portion of the autonomic nervous system resulting in numerous physiological and mental alterations. At a biological level, activation of the “fight or flight” response subsequently stimulates two endocrine systems: the hypothalamic-anterior pituitary-adrenomedullary axis (HPA) and the sympatho-adrenomedullary axis (SAM). Activation of HPA axis releases the stress hormone cortisol, a glucocorticoid, from the adrenal cortex, while activation of the SAM axis causes release of adrenaline from the adrenal medulla. The physiological effects of these hormones on the body are widespread and may include impaired cognitive function. In this study 5 healthy male and 6 healthy female subjects between the ages of 20 and 35 were subjected to a video intended to activate the sympathetic nervous system in order to investigate the effects of the fight-or-flight response on memory performance as measured by a standardized memory test. Activation of the sympathetic nervous system was quantitatively measured using EEG, GSR and heart rate.

Introduction
The human stress response can be classified as an activation of the neuroendocrine system that results in physiological as well as behavioral changes. One of the most researched human stress responses is the “fight or flight” response, which is a feed forward mechanism that prepares the body to respond to an imminent threat. The response activates the sympathetic nervous system, a division of the autonomic nervous system, and is physiologically characterized by an increase in heart rate, blood pressure, respiration, as well as other changes. At a biological level, activation of the “fight or flight” response subsequently stimulates two endocrine systems related to stress: the hypothalamic-anterior pituitary-adrenomedullary axis (HPA) and the sympatho-adrenomedullary axis (SAM). Activation of HPA axis releases the stress hormone
cortisol, a glucocorticoid, from the adrenal cortex, while activation of the SAM axis causes release of adrenaline from the adrenal medulla. Characteristic alterations in brainwave output can be used to identify sympathetic nervous system activation. Increase in beta wave and decrease in alpha wave output indicate a fear response (Fig.1). This measure is useful in determining the efficacy of experimental stimulation of the sympathetic nervous system. In this study, the correlation between alpha and beta wave output and memory performance was analyzed.

The effects of stress and the consequent activation of the sympathetic nervous on memory are complex and there is no clear-cut consensus as to the effect of stress on cognition. We seek to elucidate the effects of stress on working memory, which Funahashi states: “allows us to monitor the external world continuously, pay attention to necessary information, input wanted information, retrieve related information, manipulate and integrate information and then output appropriate information to particular brain areas”. For those reasons, working memory, either consciously or subconsciously, would seem to be critical when reacting to a stressful or threatening situation.

Working memory is governed by a region in the brain called the prefrontal cortex. A feature of the prefrontal cortex is that it contains densely-packed glucocorticoid receptors. A release of cortisol as a result of a stress response can pass through the blood-brain barrier and may have an effect on working memory. Although cortisol is required for normal physiological functions, it is not altogether clear whether glucocorticoids have a positive or deleterious effect on working memory. Basal levels of cortisol are necessary for vital homeostatic functions in the body. Cortisol maintains blood pressure, regulates plasma glucose concentration, has an anti-inflammatory effect, and functions in fetal development. However, increased levels of cortisol during stress results in different functions in the body including bone resorption, glucose sparing metabolic effects, support of sympathetic responses, erythropoietin stimulation, and as a mood elevator with the co-release of endorphins. We hypothesize that the physiological effects of activating the sympathetic nervous system, confirmed via EEG, GSR and heart rate, will inhibit working memory performance.

![Figure 1: EEG representation of standard alpha and beta wave frequency.](image)

**Materials and Methods**

**Participants**

6 female and 5 male participants aged between 21 and 35 years old (average age of 22.5 years) were recruited. Participants signed a consent form stating they did not have any pre-existing medical conditions and were willing to accept all evident and implied risks involved in participation. All participants were not informed that they would be shown a video with the
intent to induce a fear response and subsequently activate the sympathetic nervous system. Instead, in order to elicit a true fear response, participants were told that the aim of the study was to elucidate the physiological connection between relaxation, focus and memory performance.

**Physiological measurements**

All subjects were connected to a pulse oximeter to measure heart rate and oxygen levels. The pulse oximeter was attached to the subject’s forefinger of the non-dominant hand. A Galvanized skin conductor was used to measure activation of the sympathetic nervous system by quantifying sweat production. The galvanized skin conductor attached to the middle and third finger of the non-dominant hand. The subject was instructed to place their hand on the table and keep it still throughout the study. Brain activity was measured using an EEG with a total of 3 electrodes. The leads were placed on the left side of each subject’s head with one lead on the earlobe as a ground, one lead directly behind the ear, and one lead above the tip of the ear. A tight fitting swim cap was used to enhance skin conductance and to ensure accurate recordings. All measurements were collected throughout the entire experiment. Data collection was measured using Biopac Student Lab Lessons 3.7.3.

As a negative control, baselines of all measurements were collected prior to and during a “trust-building video,” consisting of relaxing ocean sounds and a consistent view of an ocean horizon. An initial baseline memory test was administered immediately after completion of the trust-building video while the subject was in a relaxed state.

**Memory Test administration/Sympathetic nervous system-inducing video ("scare video")**

The subjects were shown a grid with different colored shapes to memorize for thirty seconds timed using a stopwatch. There was a 5 minute waiting period before the memory test was conducted. After 5 minutes, the subject was given a blank grid and asked to recreate the first grid they saw using colored pencils. They were given one minute to complete the grid.

After the initial memory test and with all measurements still being collected, subjects were shown the scare video and immediately given a second memory test of identical difficulty. There was a 5 minute waiting period before the second memory test was conducted. After 5 minutes, the subject was given a second blank grid and asked to recreate the second test grid they saw (Fig. 2).

![Experimental design flow diagram](image-url)

Figure 2: Experimental design flow diagram
Memory quantification and Sympathetic Nervous System activation

Memory test results were recorded using a point scale. Subjects were awarded one point for the correct shape in the correct location, one point for the correct color in the correct location, and a half point for having any color or shape in the correct location to reward for spatial recognition (Fig. 3, 4).

<table>
<thead>
<tr>
<th>Result</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correct shape in correct location</td>
<td>+1</td>
</tr>
<tr>
<td>Correct color in the correct location</td>
<td>+1</td>
</tr>
<tr>
<td>*Any shape or color in the correct location</td>
<td>+0.5</td>
</tr>
<tr>
<td><strong>Total Points Possible Per Test Square</strong></td>
<td>+2</td>
</tr>
</tbody>
</table>

Fig. 3: Memory test scoring rubric. (*Only awarded if participant failed to redraw the correct shape or color in the correct location).

Fig. 4: Example of memory test grid (left) and graded participant response (right). One point was awarded for correct shape in the correct location. Two points were awarded for the correct shape and correct color in the correct location.

Statistical Analysis

The results of memory tests were compared to determine if there was a quantitatively significant difference in performance. Results of physiological tests were observed to determine if the sympathetic nervous system was activated. A Spearmann Rank correlation test was used to determine if there was a correlation between brain wave data collected from the EEG and memory test results. The area under each specific brain wave curve was calculated and used to determine brainwave activity during a specific time segment. In order to control the source of the data, 20 seconds of the baseline/relaxed state was collected as well as 20 seconds directly after stimulus/scare.

Statistical significance tests were performed on the collected heart rate, GSR, and EEG data by comparing baseline measurements while the subjects were resting with measurements collected immediately post-scare.
Results

Activation of the Sympathetic Nervous System

Heart Rate

Each subject’s maximum post-scare heart rate was compared to his or her baseline heart rate. Data analysis shows that there is no significant difference in relaxed heart rates compared to post-scare heart rates (P=0.9738). 5 subjects had an increased heart rate post-scare versus baseline and 6 subjects experienced a decrease in heart rate post-scare versus baseline (Table 1).

<table>
<thead>
<tr>
<th>Subject</th>
<th>Relaxed Heart Rate (beats per minute)</th>
<th>After Scare Heart Rate (Beats per minute)</th>
<th>Change in HR</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>94</td>
<td>83</td>
<td>-11</td>
</tr>
<tr>
<td>2</td>
<td>88</td>
<td>76</td>
<td>-12</td>
</tr>
<tr>
<td>3</td>
<td>94</td>
<td>85</td>
<td>-9</td>
</tr>
<tr>
<td>4</td>
<td>77</td>
<td>83</td>
<td>+6</td>
</tr>
<tr>
<td>5</td>
<td>69</td>
<td>61</td>
<td>-8</td>
</tr>
<tr>
<td>6</td>
<td>83</td>
<td>81</td>
<td>-2</td>
</tr>
<tr>
<td>7</td>
<td>76</td>
<td>74</td>
<td>-2</td>
</tr>
<tr>
<td>8</td>
<td>82</td>
<td>106</td>
<td>+24</td>
</tr>
<tr>
<td>9</td>
<td>72</td>
<td>75</td>
<td>+3</td>
</tr>
<tr>
<td>10</td>
<td>58</td>
<td>62</td>
<td>+4</td>
</tr>
<tr>
<td>11</td>
<td>79</td>
<td>85</td>
<td>+6</td>
</tr>
</tbody>
</table>

Table 1: Results of Heart Rate data collection. Number of participants with heart rate increases: 5. Number of participants with heart rate decreases: 6.

Galvanized Skin Response

Data analysis showed that there was a significant increase in mean conductance over a 20 second period from baseline to post-scare measurements (P= 5.0095x10^{-4}). A positive change in the GSR reading is indicative of an increase in conductance as a result of sweat production (Fig. 5, 6). A total of 10 subjects had a positive change in mean GSR output and 1 subject had a negative change (Table 2).

Fig. 5: Example of GSR reading during baseline relaxed state (20 second reading).

Fig. 6: Example of GSR reading during excited post-scare state (20 second reading).
Subject | Relaxed – GSR mean (microSiemens) | Scared – GSR mean (microSiemens) | Change in GSR mean |
--- | --- | --- | --- |
1 | -0.02247 | -0.06268 | -0.04021 |
2 | -0.10754 | 0.09283 | +0.20037 |
3 | -0.01056 | 0.21871 | +0.22927 |
4 | -0.01031 | 0.33189 | +0.3422 |
5 | -0.03428 | 0.09048 | +0.12476 |
6 | -0.0354 | 1.47409 | +1.50949 |
7 | -0.0599 | 0.17285 | +0.077185 |
8 | -0.14337 | 1.96808 | +2.11185 |
9 | -0.06656 | 0.31443 | +0.38099 |
10 | -0.11791 | 0.2203 | +0.33821 |
11 | 0.02023 | 0.54911 | +0.52888 |

Table 2: Results of Galvanized Skin Conductance collection. Number of participants with GSR increase: 10. Number of participants with GSR decrease: 1.

**Electroencephalogram**

Average values for area under the curve of alpha and beta waves for a 20 second time period during baseline and immediately following the scare video were compared and a statistical significance test was performed (alpha: P = 0.0215, beta: P = 0.0047). The area under the curve of both alpha and beta waves was significantly increased post-scare compared to baseline, indicating higher alpha and beta wave activity post-scare (Fig. 7, 8, 9).

![Fig. 7: Example of baseline (top) and excited (bottom) alpha wave from EEG over a 20 second interval.](image)

![Fig. 8: Example of baseline (top) and excited (bottom) beta wave from EEG over a 20 second interval.](image)
Fig. 9: Example of EEG data collection using Biopac Student Lab. Area under the curve was computed for alpha and beta waves (yellow).

Effect of Sympathetic Nervous System Activation on Memory Performance

Electroencephalogram and Memory Test Score

Using a Spearman Rank Correlation Test, there was no detected correlation between the difference in the alpha wave output and the difference in the memory test results in the relaxed and excited states (S = 159.447, p-value = 0.4127).

Likewise, there was no detected correlation between the difference in the beta wave output and the difference in the memory test results in the relaxed and excited states (S = 232.1106, p-value = 0.8723) (Table 3, 4, 5).

<table>
<thead>
<tr>
<th>Subject</th>
<th>Alpha Wave Area: Relaxed (microVolts-sec)</th>
<th>Alpha Wave Area : Scared (microVolts-sec)</th>
<th>Change in Alpha Wave Area: (microVolts-sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>27.003</td>
<td>39.282</td>
<td>+12.278</td>
</tr>
<tr>
<td>2</td>
<td>30.559</td>
<td>28.504</td>
<td>-2.054</td>
</tr>
<tr>
<td>3</td>
<td>61.874</td>
<td>194.35</td>
<td>+132.482</td>
</tr>
<tr>
<td>4</td>
<td>38.111</td>
<td>161.666</td>
<td>+123.555</td>
</tr>
<tr>
<td>5</td>
<td>28.642</td>
<td>43.446</td>
<td>+14.803</td>
</tr>
<tr>
<td>6</td>
<td>31.198</td>
<td>44.609</td>
<td>+13.401</td>
</tr>
<tr>
<td>7</td>
<td>20.302</td>
<td>19.350</td>
<td>-0.952</td>
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<tr>
<td>8</td>
<td>29.484</td>
<td>143.214</td>
<td>+113.729</td>
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<tr>
<td>9</td>
<td>27.264</td>
<td>96.448</td>
<td>+69.184</td>
</tr>
<tr>
<td>10</td>
<td>18.603</td>
<td>27.981</td>
<td>+9.377</td>
</tr>
<tr>
<td>11</td>
<td>19.968</td>
<td>81.080</td>
<td>+61.112</td>
</tr>
</tbody>
</table>

Table 3: Area under the alpha wave curve calculated by Biopac Student Lab software during 20 second period. Number of participants with increases in alpha wave activity: 9. Number of participants with decreases in alpha wave activity: 2.
Subject | Beta Wave Area: Relaxed (microVolts-sec) | Beta Wave Area: Scared (microVolts-sec) | Change in Beta Wave Area (microVolts)
---|---|---|---
1 | 25.995 | 57.939 | +31.943
2 | 37.733 | 50.704 | +12.971
3 | 116.130 | 482.531 | +366.401
4 | 99.491 | 361.747 | +262.256
5 | 147.225 | 171.197 | +23.972
6 | 39.071 | 77.409 | +38.337
7 | 22.301 | 71.816 | +49.515
8 | 38.149 | 258.733 | +220.583
9 | 32.157 | 313.617 | +281.459
10 | 36.416 | 80.819 | +44.403
11 | 69.223 | 177.273 | +108.050

Table 4: Area under the beta wave curve calculated by Biopac Student Lab software during 20 second period. Number of participants with increases in beta wave activity: 11. Number of participants with decreases in alpha wave activity: 0.

Memory Test Results

Memory test scores obtained following the scare video were found to be lower or equal to baseline for all subjects. A statistical significance test was performed and showed a statistically significant decrease in post-scare memory test score. (P=0.0017)

<table>
<thead>
<tr>
<th>Subject</th>
<th>Memory Test pre-scare</th>
<th>Memory Test post-scare</th>
<th>Change in score</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>9</td>
<td>8</td>
<td>-1</td>
</tr>
<tr>
<td>2</td>
<td>10</td>
<td>8</td>
<td>-2</td>
</tr>
<tr>
<td>3</td>
<td>9</td>
<td>8</td>
<td>-1</td>
</tr>
<tr>
<td>4</td>
<td>11</td>
<td>6</td>
<td>-5</td>
</tr>
<tr>
<td>5</td>
<td>11</td>
<td>4.5</td>
<td>-6.5</td>
</tr>
<tr>
<td>6</td>
<td>10</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>7</td>
<td>7</td>
<td>0</td>
</tr>
<tr>
<td>8</td>
<td>12</td>
<td>1.5</td>
<td>-10.5</td>
</tr>
<tr>
<td>9</td>
<td>12</td>
<td>10</td>
<td>-2</td>
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<tr>
<td>10</td>
<td>12</td>
<td>5</td>
<td>-7</td>
</tr>
<tr>
<td>11</td>
<td>10</td>
<td>3.5</td>
<td>-6.5</td>
</tr>
</tbody>
</table>

Table 5: Results of individual memory test scores. Max score possible: 12. Total number of participants with a decrease in score: 9. Total number of participants with increase in score: 0. Total number of participants with a tied scores: 2.

Discussion

The purpose of this experiment was to determine if increased activation of the sympathetic nervous system affects memory performance. With activation of the sympathetic nervous system, we expected to see an increase in heart rate from baseline compared to post-stimulus. As shown in Table 1, we found that there was no significant change in heart rate between the two conditions. We hypothesize that this is due to error in the pulse oximeter
function since we observed erratic heart rate readings throughout the studies. For future studies, we recommend using the same pulse oximeter for all participants for consistent results.

The Galvanized Skin Response was another element in determining activation of the sympathetic nervous system. As shown in Table 2, we observed an increase in skin conductance post-scare, which provides evidence of activation of the sympathetic nervous system. Unexpectedly, we observed erratic GSR data for some test subjects. We believe that movements of the participant’s fingers attached to the GSR apparatus caused these misleading data. However, the mean GSR significantly increased regardless of these imperfections in instrumentation application, indicating activation of the sympathetic nervous system.

To our knowledge, alpha and beta waves have not been used to describe sympathetic nervous system activity in relation to memory performance in an independent student laboratory setting. Additionally, our research marks the first visual representation of sympathetic nervous system activity in real time through analysis of EEG alpha and beta wave forms.

The EEG was used to determine sympathetic nervous system activation under the premise that an increase in beta wave activity and a decrease in alpha wave activity characterize sympathetic nervous system activation. Data analysis indicates that there is in fact a significant increase in both beta wave and alpha wave activity following the scare video. The unexpected increase in alpha wave activity is most likely due to electrode malfunction as a result of physical movement of the subject during experimental testing. Although this seems like a hindrance to data collection, it actually offers a unique measurement of a fear response for utilization in future studies. While the beta wave activity did increase as expected, these data may have also been affected by electrode movement at the moment when the subject was frightened. Additionally, EEG data was compared to memory test scores using a Spearmann Rank correlation test to determine if there was a correlation between change in alpha and beta wave activity and memory performance. The Spearmann test revealed that there was no correlation between alpha or beta wave activity and memory performance. One possible issue with using the Spearmann Rank correlation is the presence of identical values in both memory test scores for one subject, or ‘ties’, that brings about inaccurate data analysis with this method. In order to alleviate this issue in the future, a more complicated memory test with a larger variety of scoring components would reduce the chances of ties occurring.

Besides complications with instrumentation, our results could be improved by expanding the number of test subjects. Additionally, there was concern that the experimental design had been revealed to some of the test subjects before they were tested. Assuming this may have occurred, those test subjects who expected to be scared would have experienced a feed-forward response, thus skewing the data.

Our initial hypothesis that activation of the sympathetic nervous would result in a decrease in memory performance was confirmed even though it cannot be observed in the EEG data or the heart rate data. Future research on the topic could include a similar experimental design; however, the number of subjects and more reliable physiological testing needs to be utilized.
References


Video links:

V1. Ocean Waves - (Relaxation video): http://www.youtube.com/watch?v=-H-c1aMDsoc

V2. Follow the Red Dot - (Scare video): http://www.youtube.com/watch?v=roPrQyrbxkQ