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Article

Examining the impact of the sympathetic nervous system on short-term memory

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SUMMARY

Taking a test can feel like a life-or-death experience with increases in heart rate, sweaty hands, bouncy legs, and a racing mind. These are all signs of the sympathetic nervous system (SNS) kicking into gear. The SNS, which readies the body for fight or flight, is triggered whenever the brain perceives a threat, whether running from a dangerous animal or sitting down to take the SAT. The SNS directly influences bodily functions, which begs the question of its effect on retaining information, specifically addressing our short-term memory. To answer this question, we investigated the relationship between the SNS and short-term memory. We hypothesized that heightened visual awareness, specifically through arousing and intense visual experiences, would enhance short-term memory capabilities. To test this hypothesis, we split 20 participants into two groups. One group watched a calming video, while the other watched an intense, stress-inducing video, followed by a short-term memory test for each participant. Our results indicated that participants who watched the calming video scored slightly higher on the short-term memory test compared to those who watched the intense video. Based on the results of this experiment, we concluded that there was a negative-to-negligible correlation between acute stress and short-term memory. Our findings suggest that while the SNS may heighten visual awareness, the stress it induces has the potential to not affect short-term memory, compared to enhancing it.

INTRODUCTION

Many systems throughout the body are implemented to understand and respond to unique stimulations, from stressful to calming. The peripheral nervous system, which functions as an internal control center outside the brain and spinal cord, is divided into two main components: the somatic and autonomic systems (1). Unlike the somatic system, which controls voluntary movement, the autonomic system regulates automatic bodily functions, such as digestion, pupil dilation/constriction, breathing, and sexual arousal (1). Within the autonomic nervous system, there are three divisions: the sympathetic, parasympathetic, and enteric systems (1).

The sympathetic nervous system (SNS) manages bodily functions during acute stress-induced situations (2). When the SNS is activated, the amygdala—the brain's center for processing emotions like fear or aggression—sends signals to the hypothalamus (2). The hypothalamus then communicates with the body via neurotransmitters, inducing a physiological response through the autonomic system (3). These neurotransmitters deliver chemical signals to various organs, including the adrenal glands, heart, liver, and occipital lobe, eliciting stress responses (2). The adrenal glands, for instance, release hormones like epinephrine (adrenaline) and cortisol, triggering increased heart rate, slowed digestion, dilated pupils, and elevated energy consumption (4). These physiological changes can persist for 20 to 60 minutes after the perceived stressor is resolved (5).

Two specific SNS-induced changes, increased heart rate and pupil dilation, have been shown to correlate with working memory capabilities (6). Previous work demonstrated that heart rate fluctuations influence working memory performance, and pupil dilation is linked to variations in working memory capabilities, often enhancing performance during cognitive tasks (6, 7). Based on these findings, we hypothesized that SNS activation improves short-term memory capabilities.

To test this hypothesis, we designed an experiment that directly measured the relationship between SNS activation and short-term memory by having participants watch a specific video in their designated group and then take a memory test. We found that stress-induced SNS activation did lead to a difference in short-term memory performance. However, contrary to our hypothesis, the group exposed to stress-inducing videos performed worse than those exposed to calming videos. Our findings support a model where SNS activation during acute stress has no effect or impairs short-term memory capabilities. These findings contribute to the broader understanding of how stress influences cognitive function and underscore the variability in individual responses to stress.

RESULTS

We randomly assigned 20 participants (11 males and 9 females) into two groups and exposed each to a 2-minute video, either calming or intense, depending on the group. Then we performed a digit-span test, which directly measures short-

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term memory capabilities by having participants memorize 7 random numbers visually displayed to them for four similar rounds (8). The participant can receive a maximum score of 28 points if they correctly recall all 7 digits for all four rounds. The scores of the participants were used to evaluate cognitive performance.

The average initial and final heart rates for participants shown the intense video were 77.8 ± 9.6 beats per minute (bpm) and 79.8 ± 9.56 bpm, respectively, while participants shown the calming video had an average heart rate of 71.3 bpm before and after being shown the video (before and after average deviation of 9.36 and 10.76, respectively **(Figure 1).** These results indicate a mean heart rate increase of 2 bpm in the intense video group, reflecting heightened SNS activation, while the calming video group exhibited no change in average heart rate, suggesting no SNS activation. To account for statistical outliers within the data, the median heart rate change was also analyzed. The intense video group displayed a median increase of 2.5 bpm, whereas the calming video group showed a median decrease of -1 bpm. These findings further support the interpretation that the intense video elicited SNS activation, while the calming video resulted in no SNS engagement.

We assessed the effects of SNS activation on cognitive performance using digit-span test scores. The calming video group outperformed the intense video group, with a mean score of 24.2 ± 3.48 compared to 21.6 ± 2.6 and a median score of 24.5 versus 23 points (**Figure 2**). Notably, only two perfect scores of 28 points were observed, which were solely present in the calming video group. The difference in the mean scores between the two groups was 2.600 ± 1.626 (**Figure 2**). We found no statistically significant difference between the two groups (p=0.13). These results suggest that limited SNS activation, as observed in the calming group, can have no or a minimally negative effect on the influence of cognitive performance regarding tasks that require sustained attention and working memory.

DISCUSSION

Our results indicate a limited difference between test scores for the calming video group compared to the intense video group, highlighting no discernible correlation between acute stress and improved short-term memory capabilities. The connection between SNS activation and memory performance has been extensively studied over the decades, yielding conflicting findings. Previous research has suggested that the effect of SNS activation on memory depends significantly on individual differences and personal backgrounds (9). An experiment examined 20 studies on the relationship between SNS activation and cognitive performance (including global cognitive functioning, attention, processing speed, executive functions, memory, language, and visuospatial skills) through the measurement of heart rate fluctuations (9). Although not specifically focused on short-term memory, all forms of cognitive performance within this experiment demonstrated either a negative or minimal effect on memory capabilities, often contingent upon the individual's unique response (9).

To specifically test the effect of SNS activation on short-term memory, we used the digit-span test, which is a reliable method to test short-term memory (10). Despite these differences, our experiment and the previous experiment both show a negative or minimal relationship between SNS activation and memory capabilities (9). This variability underscores an important consideration: humans respond to stress in diverse ways. While some individuals may thrive under stress, others may falter.

These discrepancies in findings highlight the inherent complexity of this relationship, contributing to the contradictory conclusions drawn in the scientific literature about SNS activation and memory capabilities, including cognitive performance as a whole. Further testing must be done in this field with a larger sample to gain a deeper understanding of the relationship between SNS activation and memory capabilities.

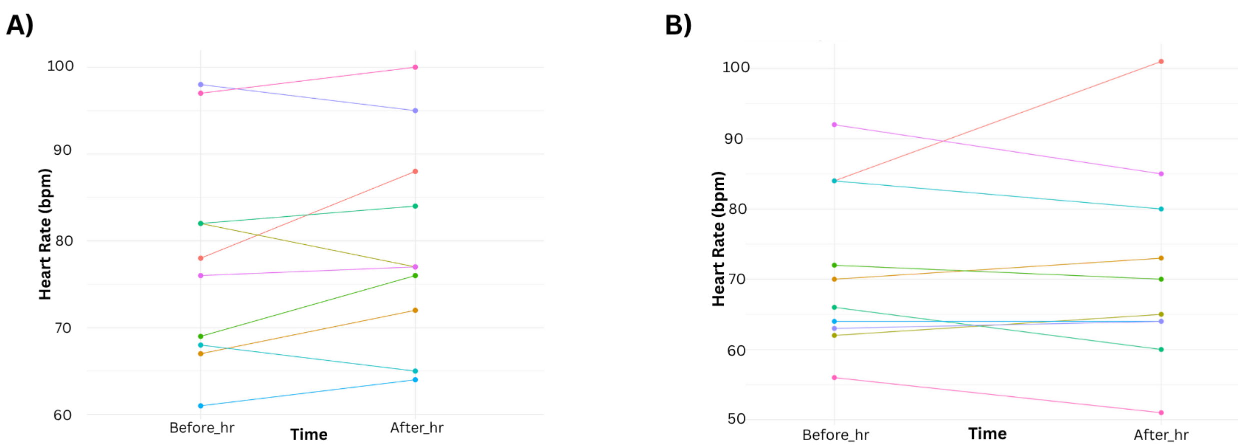

Figure 1: Initial and final heart rate measurements for each experimental group. Heart rates of participants in each group before and after watching their specific 2-minute video. Change in heart rate was used to determine the activation or deactivation of the SNS. Heart rate was measured through the Cardiio app. **A)** Initial and final heart rate measurements of participants (n = 10) before and after being shown the intense video. The average initial and final heart rates for this group were 77.8 bpm and 79.8 bpm, having a mean heart rate change of 2 bpm. Before and after average deviation values were 9.6 and 9.56. Based on these results, SNS activation can be concluded. **B)** The initial and final heart rate measurements for participants (n = 10) shown the calming video. The average initial and final heart rates for this group were both 71.3 bpm. The calming video group had a heart rate change mean of 0 bpm. Before and after average deviation values were 9.36 and 10.76. Based on these results, SNS activation was not concluded.

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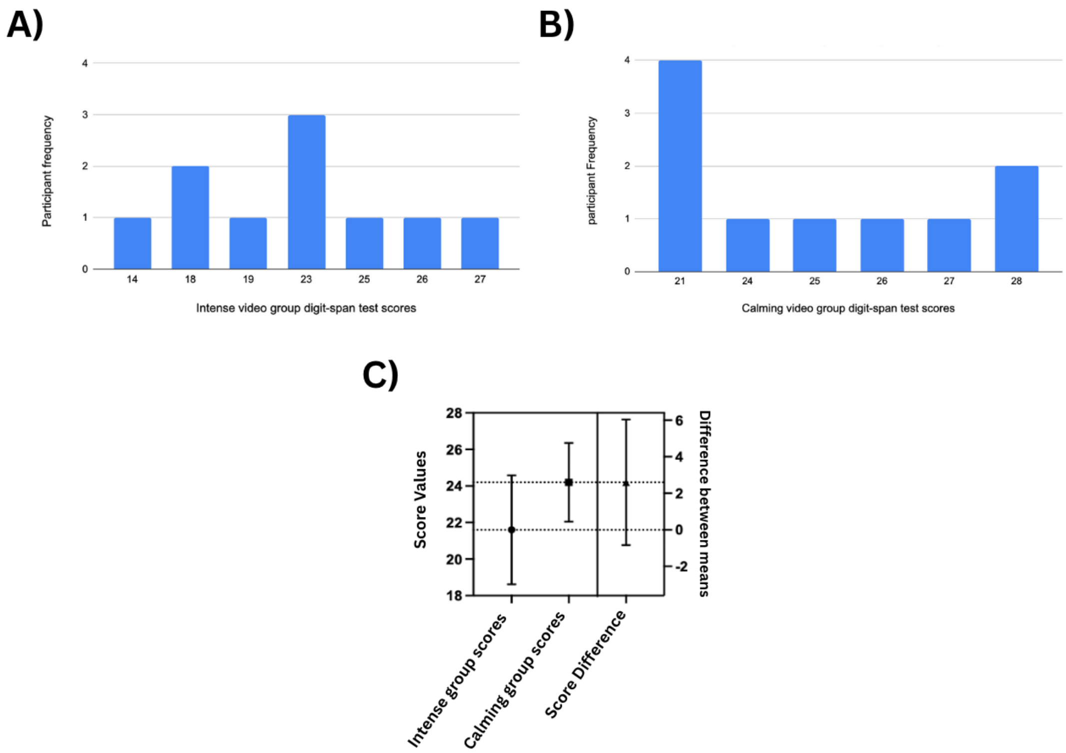

Figure 2: Comparison of digit-span test scores. We used these graphs to determine the difference between the cognitive performance of each group based on the digit-span test scores. **A)** Intense video group digit-span test scores (n = 10). The intense video group had a mean and median score of 21.6 and 23 points. **B)** Calming video group digit-span test scores (n = 10). The calming video group had a mean and median score of 24.2 and 24.5 points. **C)** Comparison between the mean digit-span test scores for the intense and calming video groups. This graph represents the overall test scores and differences between the mean score of each experimental group, which was 2.600 ± 1.626. Based on an unpaired t-test and Welsch's correction model, the P value of this experiment was 0.1290, failing the test for significant difference ($p<0.05$). These results conclude that we failed to reject the null hypothesis and that further testing must be administered. In this experiment, we witnessed instead a negative correlation between SNS activation and short-term memory. According to all of these graphs, the calming video group had higher test scores on average compared to the intense video group. Based on these results, SNS activation did not have an effect or a minimally negative effect on short-term memory capabilities.

Several factors may have influenced the results of the current experiment. The *Cardiio* app, used to measure SNS activation via heart rate fluctuations, may have introduced inaccuracies due to its inherent limitations, including glitching, finger misplacement, and potentially confusing instructions on how to correctly use the app. A more robust methodology—such as in-person measurement techniques incorporating pupil dilation or brain activity monitoring—could have improved the reliability of SNS activation data. Additionally, the remote nature of the experiment introduced potential challenges in delivering experimental instructions, leaving room for comprehension errors among participants. However, participant feedback revealed minimal confusion or concerns regarding the protocol. The limited sample size of the experiment could also have created a discrepancy in the results. Although heart rate fluctuations are crucial determining factors of SNS activation, pupil dilation and cortisol release are also important. To provide a more supportive conclusion of SNS activation, direct measurement of brain activity or hormonal release should be considered. Finally, it is essential to recognize that correlation does not imply causation. Other physiological and psychological factors can directly influence cognitive abilities that were not addressed in this experiment. For example, specific scenes in the 2-minute videos presented could have influenced visual or psychological capabilities based on previous experiences or visual cues of each participant, directly influencing cognitive abilities. Factors such as gender, visual acuity, baseline memory capabilities, and individual heart rate variability may have contributed to the observed differences in test scores beyond SNS activation alone.

The key takeaway from our study is the nuanced influence of acute stress on testing performance, particularly short-term memory. Our research reinforces the understanding that SNS activation has the ability to have no effect on short-term memory capabilities. However, a broader conclusion that should be further discussed from this experiment is that individuals respond to stress in highly variable ways—some excel under pressure while others struggle. These findings underscore the importance of considering individual differences in educational testing environments. By accommodating diverse stress responses, educators can create equitable conditions to support student success across the spectrum of perceived stressful scenarios.

MATERIALS AND METHODS

Study participants

Twenty participants (11 males and 9 females) between 18 and 25 years old participated in this study. All participants were directly asked by the researchers to participate in this experiment. Each participant signed a consent form, which was received by the researchers. Participants were randomly assigned to one of two experimental groups and were drawn from various locations worldwide (United States, Romania, Guam, and India). Every participant was fluent in English, which is why the experimental instructions were written in English.

Measuring the heart rate of study participants

We used a contact app to measure heart rate as participants being located in different areas of the world and all having access to an iPhone. According to a research article comparing the accuracy of non-contact to contact heart rate apps, measuring your heart rate through your camera lens is more accurate compared to non-contact heart rate apps, which use your eyes (11). Through the *Cardiio* app, participants measured their heart rate before and after their specific 2-minute video. They then wrote down both the before and after heart rate. Their heart rate fluctuation was then used to determine SNS activation.

The *Cardiio* app has an accuracy rate of ±1.58 bpm at rest and ±2.97 bpm during movement, making it one of the best available apps on the market for through photoplethysmography, which measures heart rate fluctuations by detecting a change in blood volume within blood vessels based on heart pumping activity (12). This particular app is seen to be successful when used for both everyday use and research, showing a 92.9% accuracy rate for determining an erratic heart rate (13).

Creating an SNS response

Short, intense videos can trigger SNS activation through stress induction (14). Due to this fact, we created two distinct two-minute videos for the experiment, including calming and intense. The calming video, shown to the control group, featured serene nature scenes and relaxing instrumental music. Conversely, the intense video, shown to the experimental group, included high-energy music and high-intensity activities, such as motorcycle rides, rollercoaster experiences, and high-speed car driving. These videos were used to either create an SNS response (the intense video) or have no effect on SNS activity (the calming video)

Assessing memory performance through the digit span test

To assess short-term memory capabilities, the digit span test, which was created by brainscale.net, was used, consisting of four rounds of the participant memorizing the order of seven random digits flashing at them (15). When addressing best practices for measuring short-term memory, George A. Miller studied and invented the concept of the *Magic Number 7 (plus 1 or minus 2)*, which was considered the best testable amount of information to give a participant when measuring working (short-term) memory capabilities (16). Because of this fact, each participant was instructed to take a digit-span test that required them to memorize seven flashing digits in a row for four similar rounds.

Collecting data from the experiment

To collect and examine the data from the experiment, the participants put their before and after heart rate measurements and their digit span test score in a Google form, which was then transferred to a Google Excel sheet to interpret the data while simultaneously creating charts.

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