EXPLORING THE IMPACT OF STRESS ON SPATIAL NAVIGATION

By

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Abstract

Stress profoundly influences cognitive functions and decision-making processes, impacting everyday tasks like navigation. Previous studies have found that when stressed, people are inclined to travel familiar routes, but they have not tested how varying the familiarity of a route may impact their navigation choices. This study explores the relationship between stress and navigation strategies, focusing on the effects of induced stress on individuals' ability to navigate a virtual environment. Twelve healthy adults participated in a series of navigation tasks under three conditions: no stress (control), physical stress (cold pressor task), and mental stress (fire environment). Cortisol levels were measured to determine the effectiveness of two different stress manipulations. Participants learned and recreated paths in the virtual city and then completed a navigation task that asked them to travel to specific locations in the virtual city. The participants' navigation strategies revealed differential effects of stress on path familiarity and navigation behavior. In the path recreation trials, participants were more likely to recreate the path they were more familiar with first. Statistical analyses suggest that stress induction did not produce a significant change in cortisol levels. However, with a small sample size with large variability, a definitive conclusion about the effects of stress on cortisol cannot be made. Path familiarity influenced participants' ability to recreate one of the two learned paths, with trends observed based on which path was more familiar. These findings underscore the complex interplay between stress, cognition, and navigation. While the data is limited with the size of our current sample, it suggests that stress may influence how individuals navigate in real-world scenarios. Further analysis in this study

and future studies with larger and more diverse samples will help to solidify these observations.

Introduction

Stress has been shown to negatively impact a person's ability to navigate and reach a destination. It is a universal experience, often occurring daily, making any function affected by stress relevant to everyone. Navigation is a routine daily task for most people, and many people experience stress or challenging situations on a day-to-day basis. Therefore, understanding how stress influences cognitive functions and decision-making is crucial, as stress may lead to poor decision-making and difficulties in navigation, potentially resulting in individuals getting lost or making potentially dangerous decisions (McEwen & Sapolsky, 1995). Virtual reality can be used to examine navigation under dynamically changing situations, finding that high-stress scenarios significantly alter navigational abilities (Varshney et al., 2024).

Stress is a natural human response to a difficult situation or challenge. The physiological stress response comprises two main components: a slower response, regulated by the hypothalamic-pituitary-adrenal (HPA) axis, and a faster response, governed by the sympathetic-adrenal-medullary (SAM) axis (Chu et al., 2024). Stress also causes the activation of the sympathetic nervous system (SNS). The SNS is responsible for what is known as the "fight or flight" response due to stress. When the sympathetic nervous system is activated during a stressful situation, it signals the adrenal glands which then release the hormones epinephrine and cortisol. The increase of these hormones in the body causes a variety of side effects, including but not limited to increased heartbeat, increased respiration rate, and blood vessel dilation (Yaribeygi et al., 2017). Cortisol, a stress hormone that is part of the slow stress response of the HPA axis, increases to almost nine times its normal levels in the body during a stressful event (Cay et al., 2018). Because of this, cortisol can be used to measure whether an individual is stressed in a situation.

Stress affects multiple areas of the brain that are involved in navigation, including the hippocampus and prefrontal cortex. It affects the hippocampus and other physiological processes, disrupting neural activity. These changes may influence an individual's cognitive performance while navigating a virtual environment. Previous studies have provided evidence that a relationship exists between stress and navigation. Stress disrupts neural mechanisms crucial for memory retrieval and prospective planning, leading to inefficient navigation strategies (Brown et al., 2020). Participants under experimentally induced stress demonstrated decreased utilization of efficient shortcut paths and increased reliance on familiar routes (Brown et al., 2020). This suggests that stress can impair the ability to flexibly plan and adapt navigation strategies, ultimately leading to suboptimal decision-making and behavior in spatial environments (Brown et al., 2020).

Navigating between locations in a known environment is a task we undertake in our daily lives, but not everyone uses the same strategy to navigate. It is a function of the hippocampus, which is hypothesized to play a role in creating spatial representations of an environment (Spiers & Maguire, 2007). The hippocampus is a central brain structure associated with learning and memory, both vital processes in navigation. Elevated cortisol levels, often seen with stress, may affect memory recall or the ability to recognize familiar routes (Yaribeygi et al., 2017). The hippocampus is suggested to be involved in recalling spatial sequences relevant to achieving goals, based on correlational findings (Brown et al., 2020). Some people may navigate using what could be described as a route-based or response-learning strategy, following well-known, familiar routes, a process thought to be supported by the caudate nucleus, while others prefer shortcuts, potentially employing a place-based strategy that is thought to be hippocampal-dependent. (Boone, 2019). Cortisol may influence these navigation strategies differentially such that stress may force place-based navigators into using route-based strategies while route-based navigators may be spared. This suggests that the stress hormone cortisol may influence the hippocampus, whereas the caudate nucleus may remain unaffected. (Boone, 2019). In previous studies, it was discovered that by inducing stress, the number of shortcuts a participant took decreased, and instead the participant exhibited a greater reliance on familiar routes (Brown et al., 2020). However, no research has yet explored whether route familiarity or route efficiency is affected by stress and cortisol levels. In our study, we aim to distinguish between these two aspects to understand their impacts on navigation when faced with a stressor. Past studies have not differentiated between route familiarity and route efficiency within the same design.

Various studies have induced stress using different methods; for instance, Brown et al. (2020) utilized shocks, while Brunyé et al. (2017) imposed time pressure. Examining navigation under time pressure as a stressor also reveals that heightened stress levels cause individuals to favor localized, route-based strategies over-reliance on global spatial knowledge (Brunyé et al., 2017). The study posits that this shift in strategy might be a cognitive response mechanism used to optimize performance under pressure in the face of cognitive demand. Contrary to these findings, a study that investigated the temporal effects of stress on decision-making highlights how various hormonal responses to stress, namely the quick increase in norepinephrine and the delayed increase in cortisol, influence cognitive processes and decision-making (Pabst et al., 2013). The study found that while moderate stress might enhance decision-making by increasing attention and rapid responses, prolonged or intense stress, which is indicated by high levels of cortisol in the body, can harm decision-making abilities. The relationship between stress hormones and cognitive processes implies that the severity of stress exposure and elevated cortisol levels would impact navigation behavior, helping to explain how people navigate under extreme stress or in a high-stress environment. Together, these studies contribute to our comprehension of how stress impacts navigation and decision-making. They underscore the nuanced influence of stress levels on cognitive responses, particularly highlighting the detrimental effects of cortisol on decision-making processes. To evaluate stress levels, salivary cortisol can be measured. In numerous previous studies, the cold pressor test (CPT) has been used to elicit a stress response (Becker et al., 2019; Boone, 2019; Buchanan & Tranel, 2008; Duncko et al., 2009; Kudielka & Kirschbaum, 2005; Pabst et al., 2013; Silverthorn & Michael, 2013; van Gerven et al., 2016).

Cold pressor stress is an experimental method involving brief exposure to painful stimuli through immersion of the hand in icy water. Widely employed in stress studies, it elicits significant activation of the autonomic nervous system and triggers mild to moderate stimulation of the hypothalamic-pituitary-adrenocortical (HPA) axis) (McRae et al., 2006; Schwabe et al., 2008). The HPA axis is a part of the sympathetic nervous system. HPA axis activation leads to the elevation of cortisol levels in the body (Hinds & Sanchez, 2022). By placing one's hand in ice water for up to 3 minutes, a cortisol increase was observed (Becker et al., 2019). This increase was observed immediately following the CPT and was seen in both women and men. Gender differences were noted in the study, with men experiencing higher cortisol differences than women (Becker et al., 2019). Other studies have shown that the CPT causes an increase in vascular sympathetic activity, an aspect of the SNS activation response. It causes an increase in blood pressure and heart rate, indicative of a physiological stress response (Mourot et al., 2009). Another study surveyed participants on their perceived stress levels and took plasma cortisol data. The study found that the CPT raised cortisol and stress levels in their participants (Geliebter et al., 2013). These results emphasize the effectiveness of the CPT in triggering physiological stress reactions and point out possible differences in cortisol reactiveness between genders.

In the current experiment, a large virtual city was used to teach participants two paths between four different stores. The participants were then asked to navigate between the stores after being exposed to a stressor. No directions or cues were given to aid the participants in their navigation between target stores in the virtual city. The paths they chose were observed to see whether they were recreating learned paths or using novel paths to navigate. There were three conditions tested, each under different stressors. The first condition was the control, which had no stressor present. Following the control was either a cold pressor task, consisting of the participant submerging their non-dominant hand in cold water, or a fire task, consisting of navigating while fire, meteors, and crashing sounds were added to the virtual environment. Both conditions were created to induce stress and a corresponding cortisol increase in the participant. The participant navigated through a large virtual city, with or without the added stressor. In this experiment, cortisol levels were measured using saliva samples. After analyzing the cortisol levels, the samples indicated the level of stress of the participants, and their ability to navigate under these conditions effectively will be analyzed by looking at how they chose their path toward their destination, and how it was affected by the change in cortisol levels caused by the stressor. This design allowed us to investigate how path familiarity and cortisol affect navigation behaviors.

Methods

Subjects

This study was managed under the approval of the University of Arizona IRB. Participants were recruited through a posted recruitment call in the online UA psychology newsletter. To participate in the study, the participant was required to be a healthy adult between the ages of 18 and 35. The individuals are also required to have no formal diagnosis of post-traumatic stress disorder (PTSD) and have normal or corrected to normal color vision to ensure all stimuli on the computer screen can be efficiently seen. We collected a preliminary sample of 12 individuals, 9 women and 3 men, so far as part of ongoing data collection. The mean age of the participants was 19.5 years old with a standard deviation of 1.3.

Materials

Virtual Environment

In the experiment, three different large virtual cities were used (Figures 1 and 2). A different city was used for each condition of the experiment so that there was no interference of memory from the previous conditions influencing familiarity. In each city, there were four stores that the participant was tasked with memorizing the locations of. The cities were counterbalanced, meaning the participants did not see the same city and task pairings universally, but rather the pairings were randomized to ensure that the city isn't a causal factor in the changing navigational performances between stress conditions.

Figure 1. An aerial view of the layout of one of the three virtual cities used in the experiment.

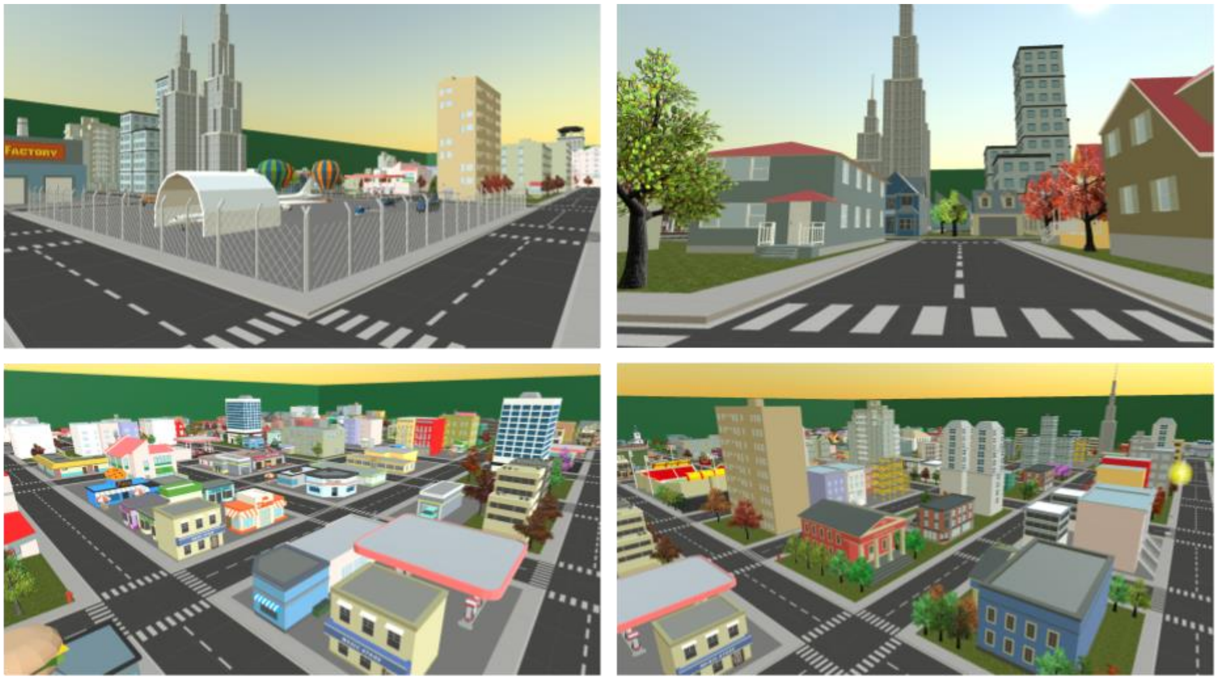

Figure 2. Four different viewpoints of one of the virtual cities.

Stressors

There were two stressors used in this experiment: the cold pressor test and the presence of fire and time pressure. In the cold pressor task, the participant placed their non-dominant hand in ice water for three minutes while looking at a camera, being told that the recording would be used to monitor and analyze their facial expressions. The warm pressor task was conducted with the participant's non-dominant hand being placed in room temperature water, which induces no stress response, using the same procedure as the cold pressor task to keep experiences equivalent as a control. In the fire task, the participant navigated for three minutes in the virtual environment where fire and meteors were in the city, accompanied by crashing and fire audio (Figure 3). The participants also had a health bar and were told that if they touched the fire they would lose health, and there was a count-up timer, introducing time pressure.

Figure 3. One of the cities during the fire condition. The health bar can be seen in the top center of the screen. Fire can be seen in various parts of the city.

Path Learning Task

The participants memorized two paths around the virtual city (Figure 4). Each path presentation consisted of a passive learning opportunity, where the participant watched from the first person point of view as their avatar made its way around the virtual city without their input, visiting each of the landmarks and the participant absorbed the city, and also an active learning opportunity, where the participants used the keyboard and mouse to navigate the avatar on the roads, following arrows that took them on the same path that the passive navigation showed them. There were six opportunities to learn the paths, four for one path, and two for the other path. The path learned four times is referred to as being the familiar path, and the path taught two times is referred to as being the less familiar path. This means that the more familiar path was shown to the participant a total of eight times (four passive, four active), and the less familiar path was shown a total of four times (two passive, two active). Of the paths learned, one was an outer path, and the other was an inner path. The outer path was a less efficient route to navigate the city, and the inner path was a more efficient route for navigating the city but was still not the most efficient path through the city. There was an equal distribution of times that the inner path was most familiar and the times that the outer path was most familiar. Each participant had at least one condition in which the inner path (I) was the familiar path, and at least one condition in which the outer path (O) was the familiar path. One example of a series of paths presented to the participant where the outer path was the familiar path is “I” “O” “O” “I” “O” “O” and an example where the inner path was the most familiar path is “O” “I” “O” “I” “I” “I.” One important note is that the less familiar path was never presented to the participant twice in a row (path learning series would never be “I” “I” “O” “O” “I” “I”). To ensure the participants had learned the paths, they were asked to recreate the inner and outer paths following the learning trials.

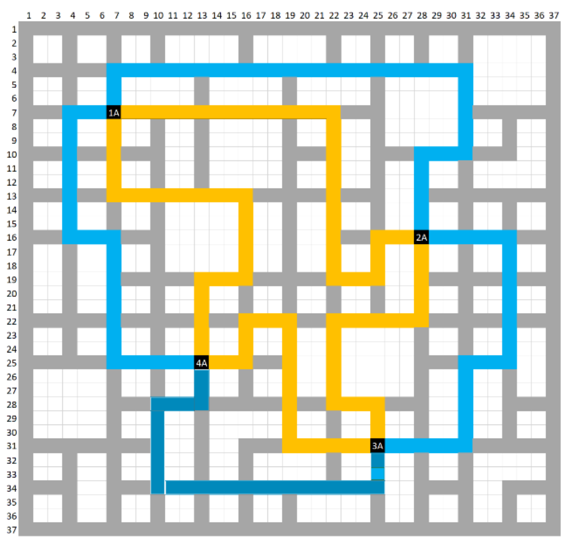

Figure 4. An example of the grid layout for one of the cities. The four stores are indicated by the black dots. An example of a learned inner path is depicted by the yellow line. An example of a learned outer path is depicted by the blue line.

Navigation Test

For the navigation test, the participant was asked to navigate repeatedly from one store to another store. These navigation trials consisted of a mix of forward, backward, and diagonal trial types (Figure 5). Forward trials took the participants from one store to another in the same direction as the learning task. The backward trials took the participants from store to store in the reverse direction of the paths that they were taught. The diagonal trials took the participants from either store 1 to store 3 or store 2 to store 4, a path that was not taught in the learning trials. The participant repeated this task for 36 trials (a total of 3 blocks with 12 trials each).

Figure 5. A grid template of a city with the four store locations indicated with red dots. Depicts what a forward, backward, and reverse trial might have been.

Saliva Samples

Saliva samples were collected to assay cortisol in the body as a proxy for stress. To take a saliva sample, the participant used a testing kit provided by Salimetrics. The participant placed a cotton swab under their tongue and left it there to become saturated with saliva for two minutes, before placing it in a test tube that was then sealed and properly labeled with their participant ID information and description of when during the task the sample was taken and in which task. Saliva samples were stored in a freezer until being sent to the lab for analysis. The samples were used to track how cortisol levels changed after exposure to the stressor, which would be indicative of a stress response occurring.

In the circumstance where the participant finished all trials of the task before the final saliva sample was taken, a simple filler task was used to occupy the participants for the remaining time. The filler experiment was a spatial awareness task where the participant was tasked with finding the angle between an object they were looking at, and another object in the area while standing at another object. There were various objects on the screen and the object the participant was standing at, looking at, and "pointing" at changed from trial to trial.

Procedure

Prior to beginning the experiment, the participants were consented and made aware of any possible risks or side effects that could occur because of the experiment. Each participant visited the lab on two or three separate occasions: either once for a four-hour session and then again at least a day later for a two-hour session, or in three separate two-hour sessions. On the first day, participants experienced the control condition, and then one of two stress-inducing conditions - either the cold pressor task or the fire task - ensuring the order of tasks did not bias the results through counterbalancing. Following experiencing either the cold or warm pressor task, the participants completed a short survey in which they answered how unpleasant the task was. They completed another brief survey at the end of the task regarding their perceived stress level.

Before completing the warm and cold pressor tasks, a saliva sample was taken to establish a baseline for what that participant's cortisol level was typically, in the absence of an external stressor. This baseline saliva sample was taken for each condition. For each task, the stressor was presented to the participant for three minutes, and then a saliva sample was taken. Saliva samples were taken two more times in 15-minute intervals while the participant was completing the navigation experiment. For the fire task, the same procedure was followed as for the warm pressor condition, except the saliva sample was taken three minutes after the participant began navigating the virtual environment, which was then accompanied by the meteors, fires, and crashing sounds.

Data Analyses Plan

Recorded data included the participant's chosen path, the duration of navigation to reach the landmark, and the distance traveled throughout the navigation process. The raw data was processed to create an image that depicted the participants' navigation strategy through the virtual city. Data analysis included looking at how cortisol levels changed following exposure to the stressor, grid overlap, and grid overlap percentages. The data collected from the participants was run through a program in R.

Results and Data Analysis

First, we tested the effect of the control condition and stressful manipulations on participants' salivary cortisol levels. The data collected generated a 3 (condition: control, cold pressor, fire environment) x 4 (time: pre, post1, post15, post30) repeated measures ANOVA with unbalanced data. There was no statistically significant difference in cortisol levels based on condition ($F(2, 4) = 0.187$, $p = 0.836$, ges = 0.012). There was a marginal difference in cortisol levels related to the time ($F(3, 6) = 3.772$, $p = 0.078$, ges = 0.005). The interaction between these terms was not significant ($F(6, 12) = 1.785$, $p = 0.185$, ges =

0.028). These results suggest that cortisol did not change due to the condition but may change with time. However, due to our limited sample size and the uneven distribution between females and males, it's challenging to draw definitive conclusions about the effects of the stressors on cortisol levels. However, there does appear to be a trend where the cold pressor shows an increase while the other stressors do not.

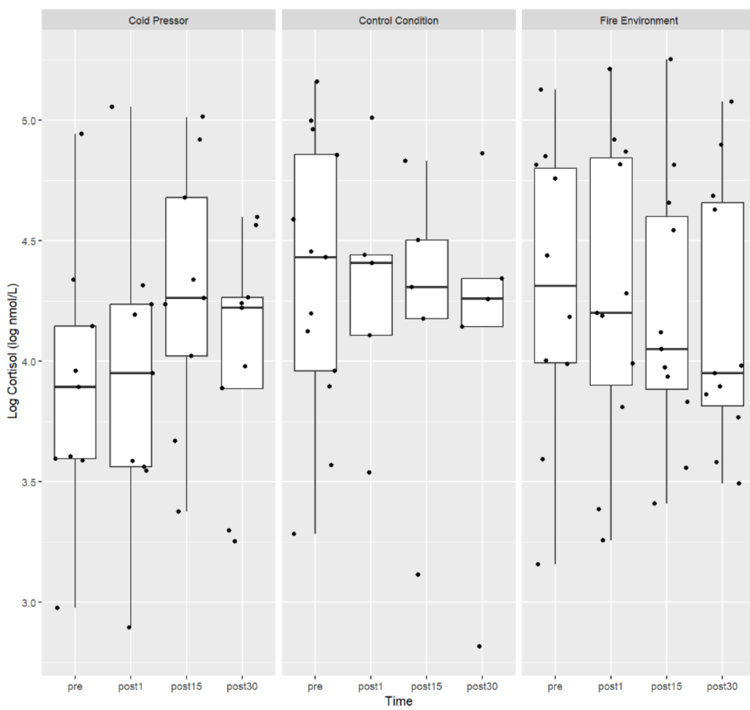

Figure 6. The plot illustrates the log(cortisol) for the three different conditions at the four different saliva collections.

Next, we looked at the order and accuracy of the recreated paths. One analysis performed was how path familiarity influenced the order in which the participants chose to recreate the paths. The participants were allowed to recreate the paths in any order they chose, and this analysis was important to evaluate whether the participants were most comfortable with the path that they had learned to a greater degree. A chi-square test of independence was performed to examine the relation between path familiarity and path recreation order. The relation between these variables was significant for both analyses performed: which path was chosen to be recreated first, X^2 (1, N = 62) = 15.032, p < 0.001, and which path was chosen to be recreated second, X^2 (1, N = 62) =6.516, p = 0.011. Participants were more likely to recreate the path that they were more familiar with whether that was the inner path or the outer path first and created the path they were less familiar with second (Figure 7). Of note, during the recreation trials, certain participants opted to replicate the same path multiple times instead of recreating both an inner and outer path. Consequently, this contributed to a weaker correlation observed in the second recreation trials, evident for the path that participants were less familiar with.

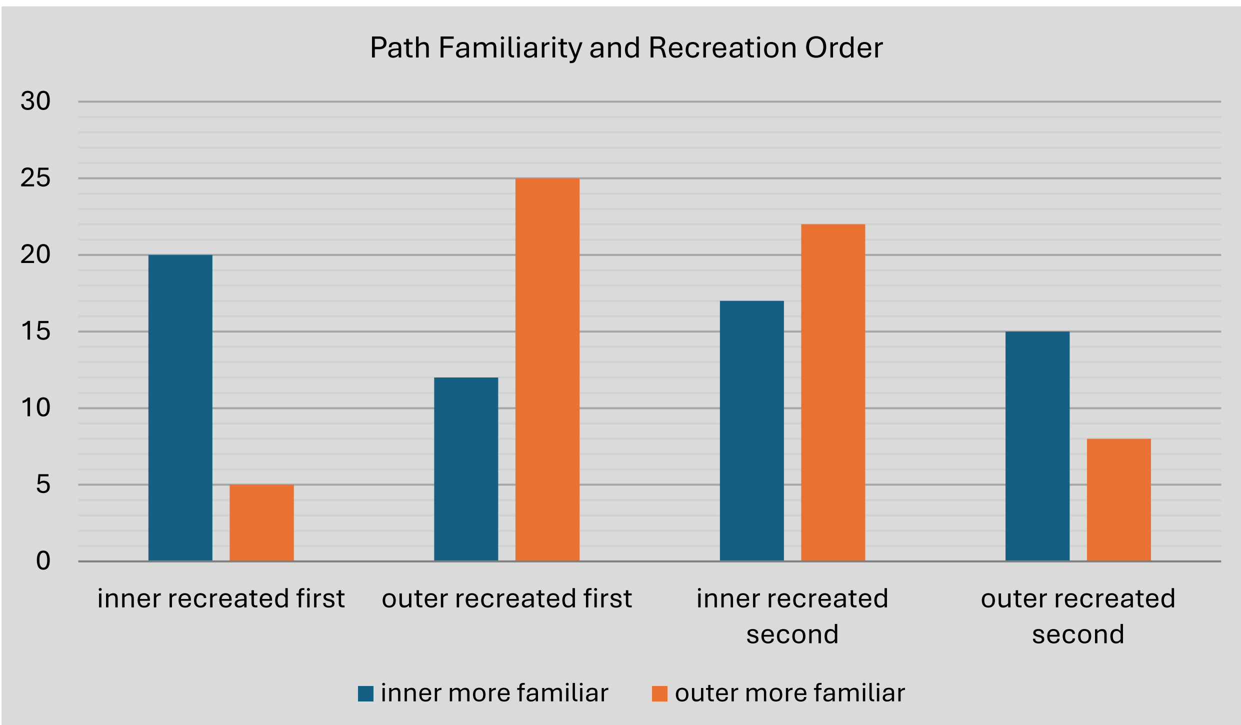

Figure 7. This chart illustrates the order in which participants chose to recreate the paths and which of the two paths was most familiar to them.

The Kruskal-Wallis rank sum test was used to analyze how well the participants remembered the learned paths. To do this, the path that was recreated was compared to the learned path the participant had been taught in the passive and active learning trials.

When recreating the outer path, subjects consistently showed a higher percent overlap compared to recreating the inner path (right panel of Figures 8 and 9). The relationship between path familiarity and path recreation accuracy was assessed using the Kruskal-Wallis test. The results showed there to be a significant association between the two variables, X^2 (1, N = 62) = 20.603, $p < 0.001$. This observation suggests a stronger alignment with the outer path when it was the focus of recreation. Similarly, when subjects were recreating the inner path, a parallel trend emerged: there was a significant increase in percent overlap with the inner path when subjects were explicitly recreating it, as opposed to when they were recreating the outer path, X^2 (1, N = 62) = 19.560, $p < 0.001$. This finding underscores that the participant was more inclined to accurately reproduce the inner path when it was the primary focus. Together, these results illuminate the influence of the intended path being recreated on participants' abilities to accurately replicate distinct paths.

Next, we tested whether participants learned the paths we taught them using a Kruskal-Wallis rank sum test. The Kruskal-Wallis test was used to calculate how path familiarity influenced a participant’s learning and recreation of the paths. When tasked with recreating the outer path, subjects exhibited a notable trend: When participants recreated the outer path and it was familiar to them, they performed well (Figure 8). However, when the outer path was familiar, but the inner path was more familiar to them, their performance was still good but not as strong as when the outer path was the most familiar to them, X^2 (1) = 4.430, $p = 0.035$. This suggests a heightened ability to replicate the more familiar outer path when the contrasting inner path posed less familiarity. Conversely, when subjects were recreating the inner path, a different trend was observed. Despite variations in which path was more familiar, there was no significant difference in their percent overlap with the inner path, X^2 (1) = 1.143, p = 0.285. Participants consistently recreated the inner route similarly regardless of whether the inner or outer path was more familiar to them (Figure 8). This finding suggests that the outer path might have been inherently easier to grasp.

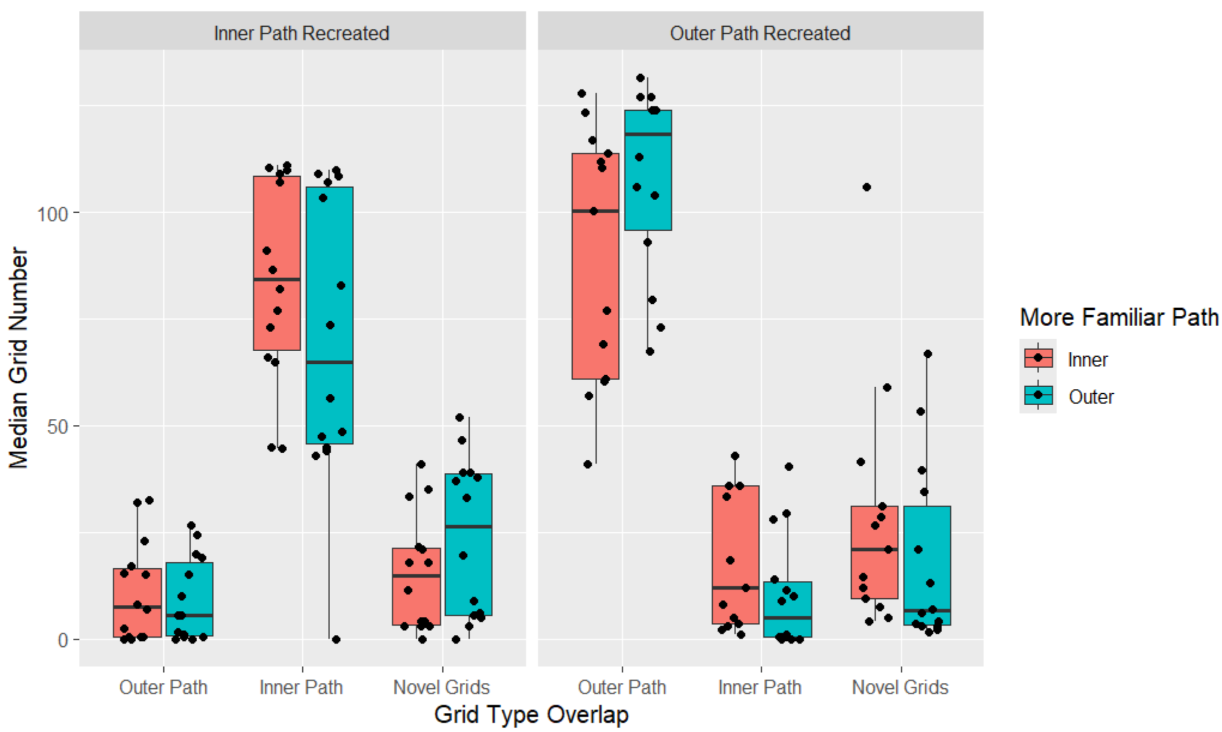

Figure 8. The graph presents the median number of grid spaces overlapping with the outer path, inner path, and novel paths when participants were recreating either the inner path (left plot) or the outer path (right plot). The inner path refers to the path that was taught to the participants and was the more efficient path. The outer path refers to the path that was the least efficient. Novel paths refer to any path that the participant took that did not overlap with the inner or outer paths. In the left part of the graph where the participant is recreating the inner path, there is the most grid overlap with the inner path grids. The same can be seen in the outer path recreation.

For the experiment to be successful, the participants needed to have learned the paths during the path learning section (Figure 9). Participants successfully navigating on the intended path demonstrates that they successfully learned the paths and were able to retrieve that knowledge for future navigation tasks.

We are presenting preliminary data as we're still in the process of collecting the full dataset. However, early numerical trends that can be seen in Figure 10 indicate that

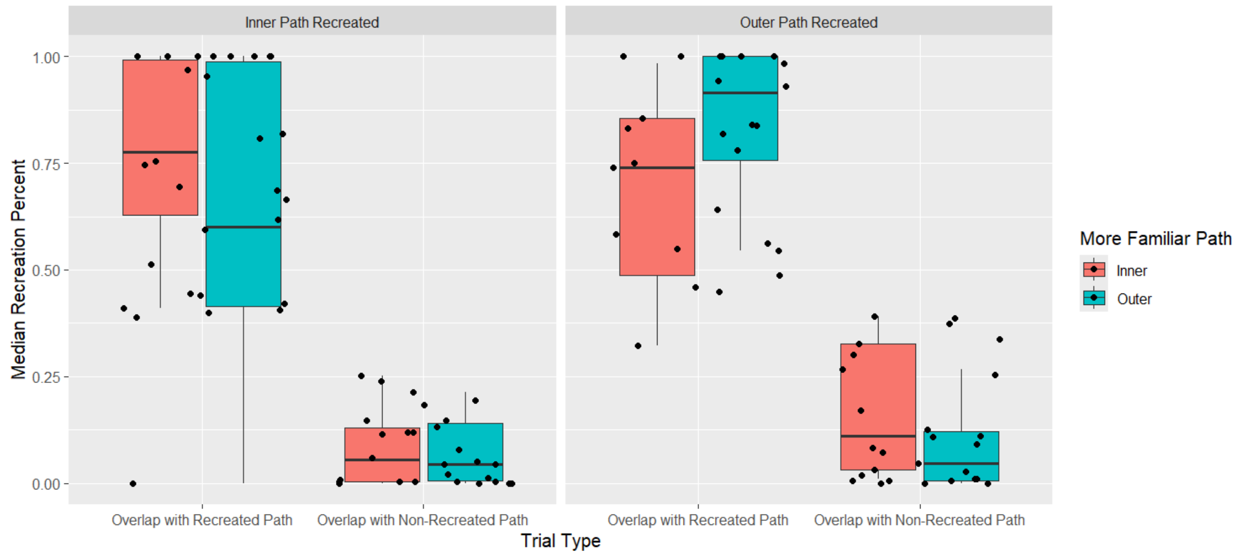

Figure 9. Depicts the median percent overlap with the recreated or non-recreated path on the y-axis. Specifically, the left plot illustrates the subjects' performance when recreating the inner path. The right plot illustrates the participants' performances when recreating the outer path. On the right side of the graph, participants who had the inner path be the most familiar effectively recreated the inner path better than those who had the outer path as their most familiar path. On the left side of the graph, participants who were more familiar with the outer path recreated the outer path more accurately than the participants who were more familiar with the inner path.

participants tend to choose inner paths more frequently, regardless of familiarity. Interestingly, the data also reveals that participants opt for novel paths more often than outer paths. This suggests that they are adept at finding and taking shortcuts, even when faced with unfamiliar paths and stressors.

The limited dataset prevents us from making definitive statements about how each condition affected navigation. Trends in navigation can still be seen by looking at Figure 10.

When there is a stressor present (as indicated by the coral-colored bars) and the inner path is the most familiar (left side of the chart), fewer outer paths are used to navigate between landmarks and more inner paths are used to navigate when compared to the control condition indicated by the green bars. Conversely, when the outer path is more familiar, there is a trend showing that more outer grids were used under the stress condition (as indicated by the blue bar) compared to the control. These trends support the prediction that stress may cause people to default to more familiar paths.

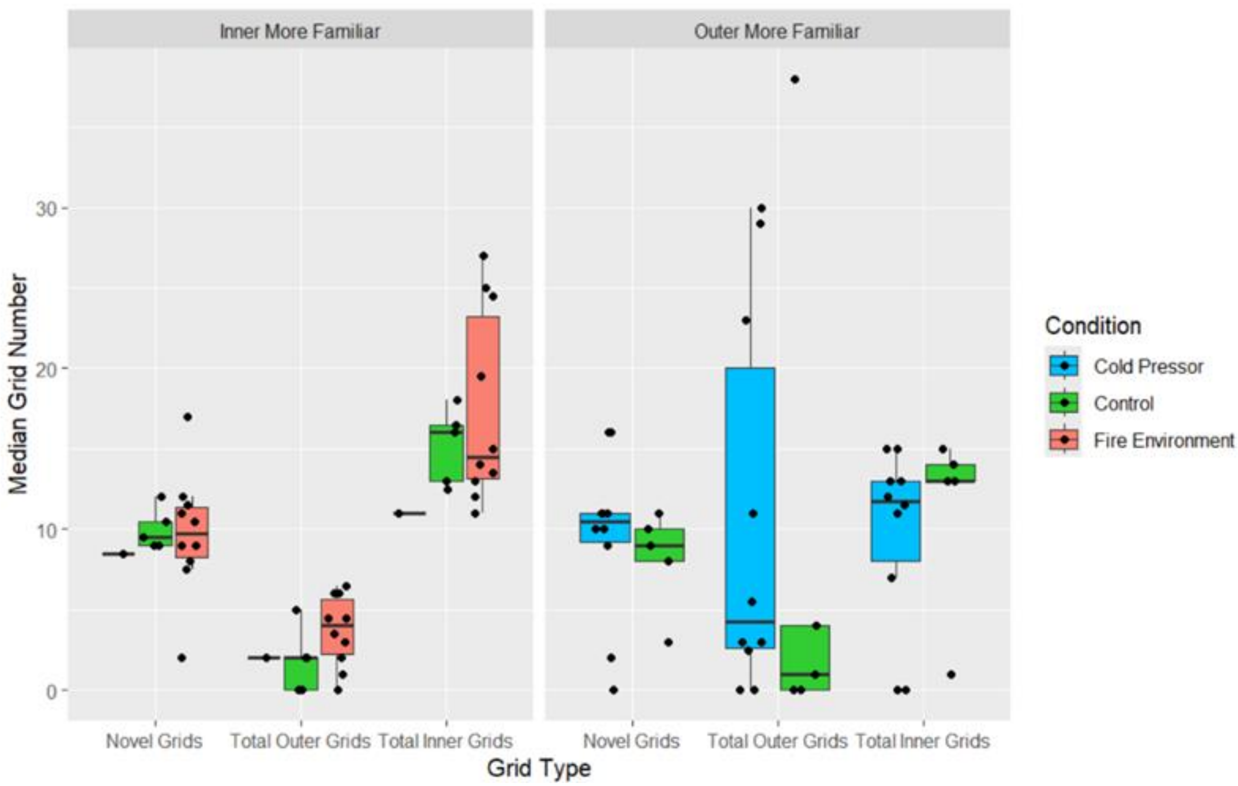

Figure 10. Depicts whether the participants used novel, outer, or inner grids. Values are raw data points with no statistical analysis. Data collection is ongoing.

Discussion

Participants in this study navigated virtual environments under various stress conditions, including cold pressor and fire tasks. They learned two paths of varying efficiencies within the virtual city to differing levels of familiarity and then recreated these paths in subsequent navigation tests. Saliva samples were collected to measure cortisol levels as a stress indicator. Preliminary findings showed no significant cortisol changes across stress conditions. These observations hint that the familiarity of the route could influence navigation choices under stress. Analyses indicated that participants recreated the more familiar path first and that both paths were learned but better performance was seen when the outer path was being recreated and was the most familiar path. These observations suggest that familiarity with the route may influence navigation decisions during periods of stress. Interestingly, participants frequently chose inner paths and novel shortcuts, highlighting their navigational adaptability even with unfamiliar routes.

The data analyzed showed no significant cortisol increase in the conditions (Figure 6). When looking at the graph for the cold compressor, a notable increase in cortisol can be seen in the third time point. Though this increase in cortisol is not significant, the trend of cortisol increase may become more apparent as more participants are run, notably, male participants who have been shown to have more pronounced cortisol increases in response to a stressor. The trends seen in the fire and control conditions are similar as they both decrease at each time point. This implies that the fire task did not induce the intended stress response. An explanation of why there is no significant cortisol difference could be that the circumstances surrounding the experiment might be different than experiments that other researchers have conducted. For example, the participant pool being composed of college students living high-stress lives might cause them to have higher initial cortisol levels which would influence how much the cortisol levels changed.

If the hypothesis that stress eliminates one's ability to produce novel paths was true, the control condition would have had more novel paths taken than the cold pressor and fire task conditions. Based on the data presented in Figure 10, there is no apparent difference in the number of novel paths taken between the control condition and the two stress conditions. However, further testing is needed to confirm this observation. Even so, trends in navigation behavior under stress conditions compared to the control condition are noteworthy. Figure 10 illustrates that when participants were navigating using a more familiar inner path under a stressor, they tended to use fewer outer paths between landmarks and more inner paths. This suggests that stress may lead individuals to rely more heavily on familiar routes. On the other hand, when the more familiar path was the outer one, there was a trend indicating participants used more of these outer grids under stress compared to the control. A definitive conclusion cannot be drawn until the complete dataset is available. An explanation as to why this result occurred is that the stressors did not raise cortisol levels significantly enough to influence navigational ability. However, this result is not expected to continue as more participant data is collected as the cold pressor test is proven to cause physiological changes associated with the stress response (Silverthorn, 2013).

Given the lack of significant cortisol results despite the known physiological effects of the cold pressor task, potential explanations for this observation were explored. At this point in the navigation study, most participants have been female. This may be a factor in why the cortisol results do not show significant variability after a stressor was presented, as female participants are more likely to have noisier and more variable data. Brown et al. (2020) chose to exclude female participants from their stress study because their stress hormone levels were more likely to be influenced by sex hormones (Kudielka & Kirschbaum, 2005). Evidence from a study on rodents suggests that estradiol, a female sex hormone, aside from its known effects on the brain, might have stress-relieving properties. Female rats subjected to repeated stress did not exhibit shrinkage in hippocampal pyramidal neurons typically observed in male rats (Wolf et al., 2001). This study posits that women are less likely to be affected by stress, therefore having less significant cortisol elevation. Cortisol data collected from male participants is more pronounced, with greater variation than data collected from female participants (Becker et al., 2019; Buchanan & Tranel, 2008). Wolf et al. (2020) also found that men showed reduced memory performance following a stress response, while women did not have the same reduced memory performance. Although an argument can be made that excluding women from a study that uses stress and cortisol analysis would be beneficial for gaining clearer results, it does not create an inclusive view of how stress would affect the general population's navigational abilities. Women and men both navigate and experience stress daily, and it does not make sense to exclude half the population and not observe their navigational reactions because their hormones are more variable.

Participants recreated the outer path better than they recreated the inner path when the outer path was the more familiar path. This aligns with the hypothesized result, that having more learning trials with a path would increase one's memory of that path. However, this result was not seen when the inner path was more familiar than the outer path, at least not to a significant degree. Once more data has been collected, the trend that does appear to enforce that the inner path is recreated more efficiently than the outer path when it is the more familiar path could potentially become more pronounced and then be significant. One reason that the outer path was more accurately recreated generally could be because the outer path was easier to learn, meaning it was remembered better by the participants and therefore was less challenging to recreate. Despite the outer path being the more learned path with higher recreation accuracy, participants tended to use more of the inner path in the navigation trials. A possible explanation is an inclination to use an efficient route over a familiar route when it came to navigating between the stores.

Future endeavors will include more data analysis to inform how the varying conditions affected the navigational abilities of the participants.

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