

# An Overview of the Effect of Stress on Working Memory

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**Abstract.** This study seeks to explore the effect of stress on working memory (WM). Stress triggers the hypothalamus-pituitary-adrenal (HPA) axis, resulting in the production of glucocorticoids (GCs) that can bind to receptors in the prefrontal cortex (PFC) and hippocampus. A substantial amount of research demonstrates that stress affects WM performance, but the details of this relationship remain unclear due to inconsistencies in experiment results. This paper categorizes stress based on duration and intensity, and reviews a selection of representative experiments that explore the relationship between specific types of stress and WM performance. The role that sex plays in this relationship is also explored through discussion of two different studies. Many of the experiments yield different with some showing that stress improved WM and others suggesting the opposite. These inconsistencies reflect how there is a need for more research to look into a potential inverted-U shaped relationship between stress and WM, and how existing methods and instruments can be improved.

**Keywords:** working memory; stress; Trier Social Stress Test; sex differences.

## 1. Introduction

Stress triggers a series of physiological responses in the body that have implications on memory formation. Most significantly, stress activates the hypothalamus-pituitary-adrenal (HPA) axis, which then releases glucocorticoids (GCs) that can bind to GC receptors in the prefrontal cortex (PFC) and hippocampus [1,2]. Stress has been discovered to influenced declarative memory and working memory (WM) [3], two functions often associated with the hippocampus and PFC, respectively.

WM is a system of information storage and processing with limited capacity, and underlies and supports cognitive processes [4]. According to Baddeley's original model, WM is divided into three main components. The phonological loop is where auditory information is shorted and unconsciously repeated, and the visuospatial sketchpad is where visual and spatial information are stored [4]. The final component is the central executive, which is less clearly identified but is usually understood as the system controlling attention and executive functions, as well as being a component connecting short-term memory with long-term memory. A considerable amount of research supports the WM model, and localization of activity in the brain has been identified for the different components. For example, executive function is usually associated with the frontal lobe. Since GCs have receptors located in the PFC, it seems reasonable that stress may influence WM performance, especially executive function.

Stress is a broad category that encompasses many different subtypes, and most experiments choose to only focus on one specific aspect. For the purposes of this paper, stress will be categorized by the duration (chronic, acute, or past exposure) and the stress level (high or low). Each categorization presents a unique perspective with which the causes, effects, and implications of stress can be evaluated. This paper will primarily focus on how past research has demonstrated the relationship between each type of stress and WM performance, and will then explore how sex plays a role in this relationship.

## **2. Impact of Stress of Different Durations on WM**

### **2.1. Chronic Stress**

Lukasik and colleagues [5] focused on the relationship of stress and anxiety with WM, incorporating a selection of battery tasks that tested the participants' visuospatial and verbal working memory. The study's participants were recruited online from a crowdsourcing site, and participants who scored more than 10 points on the 16-Item Quick Inventory of Depressive Symptomatology and self-report (QIDS-SR16) scale [6] were excluded for exhibiting depressive symptoms. The study's final sample consisted of 503 participants; all adults are from the United States. Participant stress and anxiety were respectively evaluated by through the questionnaires Short Form Perceived Stress Scale (PSS-4) and the six-item form version of the Spielberger State-Trait Anxiety Inventory (STAI-6). The researchers then used four WM tasks – simple span tasks, complex span tasks, running memory tasks, and n-back tasks – to measure WM performance.

The study revealed that age and education are significantly associated with WM performance, and so is anxiety. Interestingly, the results demonstrated that visuospatial and n-back performance decreased with age, although verbal WM remains unaffected. However, while anxiety has been discovered to be negatively correlated with all measures of WM performance, there is no significant relationship between stress and WM performance, specifically.

The study points out that the obtained results on anxiety are consistent with previous research (such as that by Moran), and the lack of association between stress and WM performance may arise from overlaps in the definition of anxiety and stress within this study [7]. As the study acknowledges in its introduction, anxiety and stress seem to possess very similar neurocircuitry and act in similar ways on cognitive processing. This is one of the major limitations of this study, and points to a need for more research detailing the similarities and differences in how stress and anxiety affect cognition, and especially on how these two states interact with each other.

There are also other significant limitations to this experiment that could be addressed by future research. For example, this study is mainly conducted through an online survey format, which is beneficial for reaching a diverse group of participants, but is also difficult to control. The researchers are unable to control the environment in which the participants are taking the test, which may lead to major discrepancies in data and performance in WM tasks, affecting data quality. The study addresses this concern in its discussion and cites research on how Internet-based studies yield results comparable to traditional experiments. However, stress and anxiety are factors that can easily be affected by the participants' immediate surroundings. It can be helpful to attempt to replicate this study using in-person interviewing techniques in a more controlled environment, and to see if the results are consistent.

This study investigates chronic stress – stress that is present over a period of time and is not immediately a product of experimental procedures. Therefore, it can be problematic when attempting to establish a causal relationship between the independent and dependent variables. That is, researchers cannot determine whether anxiety and stress are the actual causes of differences in WM performance. This is an almost inherent weakness to studies that investigate chronic conditions since it is impossible to manipulate variables. The results of this particular study seem to demonstrate that, while there is a relationship between anxiety and WM performance, chronic stress has a limited role in affecting WM performance in healthy adults.

### **2.2. Acute stress**

Acute stress is a commonly used variable in psychology experiments due to how it can be induced in a participant in a controlled setting, contrary to how chronic stress is a pre-existing condition. Acute stress is often induced through procedures including the Trier Social Stress Test (TSST), which is a standardized method that can reliably produce an increase of cortisol levels in both blood and saliva [3,8]. In the test, participants are given an anticipatory period, then asked to deliver a speech before

judges – simulating the scenario of a job interview – and to perform a challenging mental arithmetic task afterwards.

Weerda and colleagues, for example, used the TSST as a procedure when investigating how acute stress influences WM-related brain activity in healthy male participants. The study used the TSST followed by a WM task to create acute stress and measure its impact on encoding and retrieval; the researchers also used MRI imaging to examine brain activity during the two processes. The study's participants included 41 healthy adult men between ages 20 to 36, who were randomly divided into the stress and the control group. The former went through the TSST, while the latter went through another version that retained the speech and arithmetic elements but lost the evaluative and difficult aspects.

The WM task included a series of brief images of scenes and of different people's faces, and the participants were told to remember either the scenes, the faces, or just to passively watch. In the former two conditions – the active conditions – the participants were then told briefly shown an image and were asked if the image was in the series. In the passive condition, the participants were asked to identify the direction in which an arrow was pointing towards. The task took place within an MRI scanner, and the participants' answer reaction time, accuracy, and brain region activation were recorded.

The study found that the three WM task conditions (face, scene, or passive) significantly affected reaction time and accuracy, because the passive condition did not need to recall any information. Stress also significantly affected performance accuracy, with accuracy being higher in the stress group. fMRI data also indicated that the difference in stress group's brain activation between active and passive conditions in certain brain regions of the PFC and posterior parietal cortex (PPC) were greater compared to control. The stressed participants also exhibited greater differences in hippocampal activity between active trials and passive trials.

The researchers drew a connection between this study and Qin et al. [9], which observed that participants in stressed conditions exhibited lower brain activity in the right dorsolateral prefrontal cortex (dlPFC). These results are somewhat inconsistent, possibly due to the two studies' different WM tasks. Weerda used a WM task designed to isolate the encoding, maintenance, and retrieval processes from each other, while Qin employed n-back tests. The different tasks may have led to differences in cognitive processing, leading to differences in brain activation. More research will need to be done in this specific topic to draw more conclusive results [3,9].

A significant limitation of Weerda's study lies in how the WM task may encounter ecological validity issues. While the task asks the participants to encode, maintain, and recall information by using WM, the task still takes place within a narrow, cramped MRI scanner. The environment may have affected the participants emotions and stress levels further, creating uncontrolled variables that can complicate the results. The environment is highly unrepresentative of under what conditions similar cognitive processes take place in reality, thus limiting the generalizability of the results to a laboratory setting.

The study mainly focuses on the results when acute stress is induced shortly before a WM task. As the researchers acknowledge in the introduction, the time when stress is introduced is important for declarative memory, but results have been mixed for WM. This study does not look into how acute stress applied during WM processing may affect retrieval, encoding, or maintenance, which is possibly another area of exploration for future research.

### **2.3. Previous exposure to stress**

Beyond chronic stress and acute stress, past stressful experiences are also relevant in the discussion of how stress affects WM. This section primarily focuses on the study performed by Luettgau et al. [10], which aimed to investigate how acute stress, stress reactivity, and past subjective stress influence WM in terms of behavior and brain activity. The study used a within-subject design, and each participant performed an n-back task with fMRI twice, once under acute stress and once as a control condition. The participants included 34 healthy males, with no medical, neurological, or psychiatric

disorders under the criteria of the German Structured Clinical Interview for Diagnostic and Statistical Manual of Mental Disorders (SCID-IV) [11].

In the stress group, acute stress was induced by using the TSST, while the control group was simply told to read off a sheet of paper. The n-back task included both 0-back and 2-back tasks, and the data was analyzed based on the participants' accuracy and reaction time (RT). Past subjective stress experience was evaluated through an online questionnaire that included the Perceived Stress Scale (PSS-10), which evaluated subjective stress in the past 30 days.

The study discovered no significant relationship between acute stress and participant accuracy or RT in the WM task, regardless of condition. However, higher total score on the PSS-10 was negatively correlated with accuracy on the WM task under acute stress, though there is no significant relationship between the score and RT. The fMRI data generated showed that, in the stress group, there is less activation of the right dlPFC during 2-back task, though there is no significant relationship between this and past subjective stress.

This study's data suggests that acute stress does not affect WM performance, which contradicts the findings of previous studies, including the one performed by Weerda, amongst others [3]. In the discussion, the researchers hypothesize that this may be related to how timing influences how acute stress affects WM task performance. The study's WM task begins about 45 minutes after the beginning of stress induction, which may influence the extent to which stress can affect or impair WM. However, this explanation still calls for more experimental support.

One of the most interesting features of this experiment is that it uses within-subject design, which can help diminish the effect of individual variation, especially in terms of cortisol and stress reactivity. This contrasts with Weerda's experiment, where individual differences between participants could influence the quality of the results. Through the within-subject design, Luettgau were able to determine how experience with previous subjective stress could affect WM performance. This also introduces an element of uncertainty into other studies that focus on acute stress and WM, because past subjective stress can act as a confounding variable during the study.

### 3. Impact of stress of different levels on WM

While different forms of stress seem to affect WM performance differently, varying levels of stress also need to be considered when evaluating the effect of stress as a whole. Lewis, for example, examines how variations in the intensity of examination stress – a form of naturalistic stress – affects WM [12]. The authors then discussed the results in relation to potentially using an upside-down U-shaped curve to model the relationship between stress and WM performance.

The study's participants included 67 undergraduates, and they were asked to come to the lab for two sessions, corresponding to one high examination stress session and one low examination stress session. The participants were asked to fill out the STAI State Inventory, the STAI Trait Inventory, and PSS-14, which served as assessment instruments for stress levels. Next, the participants performed Digit Forward and Digit Backward tests, both of which are subtests of the Digit Span test and serve to evaluate WM performance.

The results show that WM task performance varied significantly between the high and low examination stress sessions, with better overall performance during sessions with high examination stress. The Digit Forward subtest showed no session-related performance differences, but performance on the Digit Backward subtest was significantly better in the high-stress session compared to the low-stress session. That was the only significant relationship discovered for WM performance. All indicators of subjective stress were measured to be significantly higher in the high examination stress period.

These results demonstrate how higher levels of stress seem to improve WM performance. However, as the authors note in the discussion, there are a multitude of factors that need to be considered. For example, while these results are consistent with some studies, they are inconsistent with the results of other studies that show that stress leads to worse WM performance, including the results of the

aforementioned Luettgau. The authors propose that the effect of stress on WM performance be nonlinear or indirect, and may instead resemble the inverted-U relationship previously discovered by Lupien [13]. This relationship suggests that high levels of stress, often achieved in labs through injection of hydrocortisone, lead to poorer WM performance, while low or moderate levels of stress either do not affect WM performance or can have improving effects. More research is needed to approach more decisive answers regarding the potential non-linear relationship between stress levels and WM performance.

There are also other limitations to Lewis et al. (2001). Most notably, there may be a large number of extraneous variables within the study. Given the nature of examinations, the students' WM performance may very well be influenced by frequent processes of memorization or information manipulation that are associated with examination preparation. These processes likely would influence WM performance, especially in executive functions. Thus, there is no way to find out whether improved WM performance during high examination stress sessions is a result of heightened stress or increased practice for exams. This severely limits the generalizability of the study's results, which would require more future research to alleviate.

#### **4. Impact of sex on the effect of stress on WM**

Beyond the duration and level of stress, there are also many moderating factors that influence stress's effect on working memory. Notably, research has shown how sex can play a significant role in the process. Many studies, such as those performed by Weerda and Luettgau, chose to focus on male participants because oral contraceptive use and hormonal cycles in females may act as confounding variables. However, this inevitably limits the studies' findings to male populations. Studies such as Cornelisse, Schoofs, and Zandara have demonstrated that WM in women is differently affected by stress compared to men.

In Cornelisse, both male and female participants were from the University of Amsterdam, and they were divided into the stress group and the control group. The stress group went through the TSST, and a modified, non-stressful version of the test was used in the control group [14]. WM performance was then evaluated through n-back tasks, including 0-back, 2-back, and 3-back tasks, and reaction time (RT) and accuracy were recorded. Salivary cortisol was collected at ten different points throughout the experiment.

The study found that the stressed participants experienced a significantly higher cortisol level increase after the TSST. For stressed participants, cortisol levels in males increased more than in both naturally cycling females and females taking contraceptives. Notably, cortisol level changes in females who were taking oral contraceptives were especially blunted. In the n-back task, there was a lack of significant difference in performance accuracy between the stress and control groups for performance accuracy, nor did sex demonstrate any effects on correct responses.

Participants reacted faster in the 2-back task than in the 3-back task, which was expected due to WM load differences. In female participants, different conditions demonstrated no effect on RT. Male participants in the stressed condition had shorter RT when performing the 2-back task than those in the control condition, although no significant difference was found in other difficulties of the n-back task.

These results suggest that stress does not affect WM performance accuracy, and that females demonstrate no stress-induced WM effects. This is, as the original study mentions in the discussion, in line with previous research that found that WM of males are more affected by stress. Cornelisse proposed several possible explanations, with the first being different hormonal states in females and males. Previous studies on rats have demonstrated that sex hormonal systems influence how stress affects memory [16]. Cornelisse also shows how females show less change in cortisol levels after being stressed compared to males, which is supported by the results of other experiments, as discussed in the original paper. Possible explanations for this specific difference include how different stages of the menstrual cycle could influence hormonal balance in females, in turn affecting cortisol response.

While Cornelisse successfully replicated the results of some previous studies, there are also a number of limitations to the study itself. A notable example would be how most female participants were taking oral contraceptives. Since oral contraceptives have shown to significantly impact cortisol change after stress, it would be optimal for this particular variable to be isolated when discussing the results. An investigation on the specific relationship between taking oral contraceptives and WM performance under stress could be a potential subject of interest for future research.

Another aspect of this study that can serve as both a limitation and a strength is the very narrow age range of participants. All participants are between 18 to 25 years of age, which means that their brains and bodies are only representative of this specific age group. While this removes potential extraneous variables, it also means that the study's results cannot be generalized to older or younger populations that are likely undergoing different neural and hormonal processes. After all, it is very unlikely that an older female undergoing menopause would have the same hormonal mix as a 20-year-old female, and if hormones play a large role in shaping the effect of stress on WM, age must also be considered.

In their discussion, Cornelisse also point out that hormonal states in females vary during different phases of the menstrual cycle, and that this present study was unable to isolate the stages as a variable because of uneven distribution across participants. This could perhaps be explored more deeply in future research, as it bears significance to understanding WM memory and stress in females.

Schoofs's study is an example of a study that was influenced by the results of Cornelisse, and it also aimed to study sex differences in how stress affects WM [15]. Schoofs consists of two different experiments, and both consisted random allocation of participants to either the stress or control group, followed by the TSST to induce stress and a WM performance task. The main difference between the two experiments was that Experiment 1 used only digits in the n-back tasks to assess WM performance, while Experiment 2 included both images of varying emotional valence and digits in the n-back tasks. Additionally, only one level of difficulty (2-back) was presented in Experiment 1, while two levels (2-back and 3-back) were presented in Experiment 2. In both experiments, both male and female participants were recruited, and all female participants were not taking any hormonal contraceptives, an improvement from Cornelisse. The female participants also self-reported which half of their menstrual cycle they were in.

The results of Experiment 1 indicated that there was no difference in the percentage of correct responses for condition or for sex. However, stressed males had shorter RTs compared to unstressed males; the opposite was true for females, with stressed females having longer RTs compared to unstressed females. Menstrual cycle half also did not have any relationship with stress effects or WM performance.

The results of Experiment 2 found no main effect of sex, treatment, task difficulty, and stimulus type (image or digit) on reaction time. The only effect observed was that stressed males showed shorter RTs in the difficult 3-back tasks compared to their control group counterparts, while stressed females had longer RTs in the 3-back tasks compared to control. However, this descriptive data was not found to be significant in post hoc t-tests. Analysis also found that, accuracy was lower on 3-back tasks compared to 2-back, and accuracy was lower for image stimuli than for digits. No other main relationship was established for accuracy. Menstrual cycle half also showed no relationship with WM performance (both RT and accuracy) or with stress effects.

The results of Schoofs can successfully address some limitations previously discussed under Cornelisse. For example, self-reported menstrual cycle half was isolated as a variable, and it was shown to have no relationship with any other variables. While the reliability of the self-reports are somewhat low due to the dependence on self-reports, the results do decrease the possibility that the menstrual cycle has a significant role in determining how stress influences WM in females. Schoofs et al. also made sure that the females involved in the experiments were not taking oral contraceptives at the time, which improves the quality of the results, as an extraneous variable is removed.

This study agrees with the results of Cornelisse in multiple places, such as how male WM performance seems to improve under stress. The authors do note that this does run contrary to the

results of some studies that show that stress impairs WM performance in males. The inconsistency could perhaps be attributed to the inverse U-shape relationship between WM performance and stress, as mentioned in the previous section of this paper. Schoofs also shows how female WM performance is impaired by stress, which was not observed in Cornelisse's experiment. A speculative explanation that Schoofs et al. suggested in the original paper's discussion was that females and males may be situated at different places on the inverse U-shape relationship between WM performance and stress. However, this is largely speculative and would require more theoretical and empirical evidence for support.

## 5. Discussion

After examining several notable studies, several main points for potential improvement can be identified. First and foremost, most studies define stress as psychosocial stress, and the TSST is amongst the most common ways of inducing acute psychosocial stress in a laboratory environment. An implicit assumption underlying this method is that the participants will react in similar ways to psychosocial stress. However, as Luettgau pointed out, previous exposure to stress within 30 days of lab testing could potentially influence the participants' WM performance. Thus, it is difficult to isolate the effects of induced stress on WM performance. Most of the studies mentioned above do not address how previous stress could act as a confounding variable when evaluating the relationship between stress and WM performance. Studies may yield different results if participants were asked about their past experiences through instruments such as PSS-14, and if this particular variable was accounted for in the results. This does not automatically mean the results of studies investigating acute psychosocial stress are invalid or unreliable, but merely that the discussion of chronic or past stresses may lead to more meaningful conclusions.

A second problem that can be identified is how different experimental assessments of WM performance may require the participation of different parts of WM, which may lead to construct validity considerations and difficulties in comparing different studies. For example, Lukasik, Luettgau, Cornelisse and Schoofs all used n-back tasks to assess WM performance. On the other hand, Lewis used Digit Span tests and Weerda used another assessment. The different methods used by different researchers make comparison between studies difficult, as it is unclear whether the tasks reflect the same component of WM. Research in the past has also shown that the n-back task itself failed to demonstrate convergent validity with other WM performance tasks [17], which puts doubt on whether it is really a reliable method of assessment. Additionally, the WM model itself consists of multiple parts, and there is no answer yet as to which specific part of the model is being influenced by stress.

Another issue that should be considered is the participant selection. The participants in many studies are university students [12, 14, 15], most of which are young adults under the age of 30. These participants are young people who regularly engage in learning and have yet to experience certain structural changes in the brain that usually come with age. They are hardly representative of human populations as a whole. There is a distinct lack of research on the effect of stress on WM performance in older, working populations, which limits the generalizability of conclusions. Furthermore, the lack of conclusions regarding how sex plays into the dynamic between stress and WM can be at least partially attributed to the selection of male participants over female participants. To approach insightful conclusions that apply for a greater part of society, more research has to be done on female participants.

Most importantly, more research is needed to resolve the inconsistencies in current research. While it seems likely that stress and WM performance do not affect each other linearly, there is a limited number of possible explanations. One such explanation is the inverted U relationship, but even that theory would require more research to be convincing and supported. The influence of sex on how stress affects WM performance is similarly riddled with inconsistencies, which is at least partially

due to the smaller number of studies that include female participants. More research is needed to approach a conclusive answer to the research question proposed.

In the future, research could be oriented towards exploring the relationship between the different factors interacting with the main known correlates of stress. For example, participant cortisol level is usually perceived as a good indicator of stress. However, the difference in how cortisol levels are affected by stress in males, females, and females taking oral contraceptives suggests that there are perhaps more factors playing into this relationship. An interesting factor that could be explored is how cortisol levels correlate with subjective perception of stress in individuals whose cortisol level differences are blunted by medicines or drugs, such as oral contraceptives.

Research could also target how biomarkers including cortisol levels can act as an indicator of “optimal stress levels.” As previously discussed experiments have shown, a certain level of stress can improve WM performance, can have important implications in school and business settings. However, since research has also shown that previous exposure to stress can hinder WM performance, it may be helpful to ascertain within what range is stress commonly beneficial for individuals.

## 6. Conclusion

In conclusion, this paper sought to discuss current literature regarding how stress affects WM performance. Specifically, the studies performed by Lukasik, Weerda, and Luettgau are analyzed based on the different durations of stress they examine; Lewis et al. (2008) is interpreted in terms of how it provides a possible explanation for observed inconsistencies in experiments; Cornelisse and Schoofs are discussed based on their discoveries of how sex plays a role in the relationship between stress and WM. While there are vast amounts of research surrounding this topic, there are still many inconsistencies and limitations to what current literature has concluded. The causes of these limitations may include poor construct validity, different methods of measurement, and limited representation in participant selection. Improvements in experiment design and research direction may prove helpful in furthering understanding of this topic, which can hold significant implications when applied to daily life in school and business settings.

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