DISSERTATION

# MECHANISMS OF PROSPECTIVE MEMORY PERFORMANCE: EXPLORING DEPRESSION-RELATED IMPAIRMENTS IN METAMEMORY, CUE DETECTION, AND INTENTION RETRIEVAL

Submitted by

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# ABSTRACT

## MECHANISMS OF PROSPECTIVE MEMORY PERFORMANCE: EXPLORING DEPRESSION-RELATED IMPAIRMENTS IN METAMEMORY, CUE DETECTION, AND INTENTION RETRIEVAL

Prospective memory (PM) is a critical cognitive skill describing our ability to create and perform future-intentioned goals. College students require a high level of PM abilities to complete their assignments for school, attend work and class regularly, and balance their social life with studying and personal care. PM can be divided into its two subcomponents: cue detection and intention retrieval, which can be measured using electroencephalogram/event-related potentials (EEG/ERPs). Impairments in PM may be explained or predicted by variations in these specific neurophysiological components. Metamemory, or how an individual thinks of their own memory abilities, may predict overall PM performance; metamemory guides how an individual encodes their intended future goal, monitors the environment for the cue, and sets reminders to complete their goal. Since the components of PM are necessary to successfully perform a PM goal, and metamemory may interact with the neurocognitive underpinnings of PM, metamemory beliefs may also predict cue detection and intention retrieval. Further, metamemory beliefs and the neurocognitive components of PM may be sensitive to psychological disorders, such as depression, which could impact overall PM performance. Depression is a particularly prevalent and debilitating disorder, especially among college students, and could play a role in these various factors involved in PM.

This dissertation is made up of three papers that examine the neural and cognitive mechanisms involved in the relationship between depression and PM. The first paper characterizes how metamemory beliefs predict the neural and behavioral components of PM. The second paper assesses how depression levels predict the neural components of PM and metamemory beliefs. Further, Study 2 assesses how the relationship between depression and the neural components of PM varies based on metamemory beliefs. Finally, the third paper builds on Studies 1 and 2 by examining how depression levels relate to behavioral PM performance, and if metamemory beliefs or the neural components of PM may explain or contribute to this relationship. Altogether, this dissertation clarifies the cognitive, neural, and psychological factors that may support or harm PM skills, which could help inform intervention strategies to strengthen and protect future-oriented goal setting abilities.

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DEDICATION

*To my family, who has given me everything.*

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# CHAPTER 1: MECHANISMS OF PROSPECTIVE MEMORY PERFORMANCE: EXPLORING DEPRESSION-RELATED IMPAIRMENTS IN METAMEMORY, CUE DETECTION, AND INTENTION RETRIEVAL

## 1.1. INTRODUCTION

Prospective memory (PM) is the ability to create and perform future tasks and goals (Einstein & McDaniel, 1990). It is essential for successfully performing high-level goals in college populations, including succeeding in their classes and jobs, maintaining their physical, emotional, and mental health, and balancing their social life. PM can be broken down into two underlying cognitive components: cue detection and intention retrieval. Cue detection refers to the ability to notice the appropriate moment when a future-oriented goal should be carried out. Intention retrieval refers to recalling the correct future-oriented goal. These components can be measured using electroencephalogram/event-related potentials (EEG/ERPs), with cue detection represented by the N300 component and intention retrieval represented by the prospective positivity component (Chen et al., 2015). Measuring the cognitive factors of PM using neurophysiology, as well as behavioral PM performance, is critical as it allows researchers to determine if the neural components contribute differently to behavioral PM abilities in various contexts or populations.

Historically, PM has primarily been measured behaviorally, but recent research has emphasized the importance of also examining the distinct underlying neurocognitive components of PM. These components may be able to help researchers differentiate potential contributors to PM behavioral difficulties commonly seen in neuropsychiatric disorders. For example, Chen et al. (2015) demonstrated that adults with schizophrenia had decreased behavioral PM performance, as well as a reduced intention retrieval response, measured using EEG/ERPs. This relationship was not seen for cue detection. Chen et al. (2015) indicated that schizophrenia-related impairments of behavioral PM may be explained by more distinct issues with the intention retrieval component of PM rather than by the cue detection component. Further, Ji et al. (2022) examined similar outcomes with children with learning disabilities. They found that children with learning disabilities had decreased behavioral PM performance, and a decreased cue detection response, measured using EEG/ERPs. This relationship was not seen for intention retrieval, leading the researchers to suggest that cue detection could be more implicated in behavioral PM deficits associated with learning disabilities (Ji et al., 2022). Based on these studies, remediation strategies could specifically target intention retrieval capabilities for adults with schizophrenia, and cue detection for children with learning disabilities to strengthen overall behavioral PM performance (Chen et al., 2015; Ji et al., 2022). By examining behavioral PM performance and the separate neurocognitive PM components, researchers can better understand the cognitive factors that may strengthen or weaken future-oriented goal setting, ultimately supporting the success and wellbeing of college students.

Metacognition and its related form of cognition, metamemory, also likely play an important role in PM performance, as metacognitive and metamemory abilities relate to how people decide to implement memory strategies, reminders, and coping mechanisms. Metacognition describes the ability to observe, direct, and regulate one’s own cognition, with one’s memory abilities being the crux of metamemory (Flavell, 1979). Metamemory is a more specific type of metacognition that refers to the knowledge and awareness of one’s memory abilities (Schwartz & Metcalfe, 2017). For example, metamemory abilities may be employed when an individual evaluates whether they will be able to remember a phone number, resulting in potentially positive or negative metamemory beliefs: e.g., “I have good memory, I am confident I will be able to remember this phone number later,” or “I have poor memory, I will immediately forget this number.” Based on these metamemory beliefs, somebody may choose to write down the phone number, or they may choose to rely on their recall abilities, which can impact their memory performance.

Individuals use metamemory beliefs to predict their own PM performance, which may relate to cognitive effort placed towards the neurocognitive components of PM. Cognitive effort is the degree of engagement a person puts towards demanding tasks, with higher cognitive effort likely strengthening performance of the task (Westbrook & Braver, 2015). Based on their metamemory beliefs, a person can then decide if they should spend more cognitive effort searching their environment for the cue (i.e., cue detection), retain the intended goal in their memory (i.e., intention retrieval), or implement different strategies to support their goal (Kliegel et al., 2008). Previous research has indicated that when making metamemory-based predictions of future behavioral PM abilities, adults are underconfident, and their metacognitive beliefs predict their behavioral PM performance (Knight et al., 2005; Meeks et al., 2007; Schnitzspahn et al., 2011). Although it is likely that metamemory beliefs also contribute to cue detection and intention retrieval, no previous studies have used EEG/ERPs to assess how metamemory beliefs may predict the separate neurocognitive components of PM.

Although further research has indicated that behavioral PM and metamemory are sensitive to various psychological disorders, such as depression, there are still various gaps in the literature here as well. Depression is a highly prevalent psychological experience in college students that is associated with impairments in both PM and metamemory (Fitzgerald et al., 2022; Irak et al., 2023; McFarland & Vasterling, 2018; Smith et al., 2011). Based on the symptoms of depression, this disorder can be distinctly tied to the neurocognitive components of PM. For example, the difficulty in concentrating or directing attention associated with depression may make it difficult to monitor the environment for a cue (i.e., cue detection). General and retrospective memory issues associated with depression may result in difficulty recalling and performing a future-oriented goal (i.e., intention retrieval). Despite the possibility that depression is related to the neurocognitive components of PM, and the importance of these components in behavioral PM performance, no previous studies have used EEG/ERPs to assess how depression may impair cue detection and intention retrieval.

Overall, the mechanisms of depression-related cognitive impairments are not well understood for behavioral PM or metamemory (Kessler & Bromet, 2013), and relationships between the neurocognitive components of PM, metamemory, and depression have not been explored. Specifically, no previous studies have used EEG/ERPs to investigate how depression may interact with metamemory beliefs to predict the neurocognitive components of PM, or how depression may interrupt cue detection and/or intention retrieval during a behavioral PM task. Further, while previous literature indicates that cue detection, intention retrieval, and metamemory beliefs are all involved in PM abilities, and depression likely impairs both metamemory and behavioral PM, no study has examined the combined role of these factors on behavioral PM. Based on these gaps in the literature, this dissertation has three objectives, which are addressed in three studies:

Study 1) Examine the role of metamemory in the two neurocognitive components of PM, cue detection and intention retrieval. Also, examine the role of metamemory in behavioral PM performance.

Study 2) Examine the role of depression in differences in neurocognitive PM components and metamemory beliefs. Also, assess if metamemory beliefs moderate the relationship between depression levels and the neurocognitive components of PM.

Study 3) Examine the role of depression in behavioral PM performance. Also, assess if the neurocognitive PM components help explain depression-related behavioral PM impairments, and if this relationship is further modified by metamemory beliefs.

Ultimately, these three studies build upon each other to test a potential moderated mediation to determine how metamemory, depression, and the neurocognitive components of PM are all involved in behavioral PM performance. See Figure 1 for a conceptual layout of how the studies work together to examine a potential moderated mediation model. In all studies, the neurocognitive components of PM are characterized by measuring the N300 and prospective positivity ERP components. The results from Study 1 would support the idea that metamemory beliefs are implicated in behavioral PM performance and the separate neural components of PM. The results from Study 2 would indicate that depression predicts PM neural components and metamemory beliefs, and that metamemory beliefs and depression interact when predicting one or both PM neural components. Finally, the results from Study 3 would determine if behavioral PM is impaired in depression and if this relationship is explained by one of the neural components of PM (i.e., the hypothesized mediation). Based on the findings from Studies 1 and 2, Study 3 would also investigate how metamemory beliefs and the neural components may both contribute to the relationship between depression and behavioral PM, ideally testing a moderated mediation. With the information from this dissertation, researchers could advise college students on how to think about their own memory abilities, implement memory strategies, and carry out their intended goals. Based on the importance of PM in accomplishing personal, professional, and academic goals, these results have the potential to support the success, health, and well-being of college students, especially students experiencing depression.

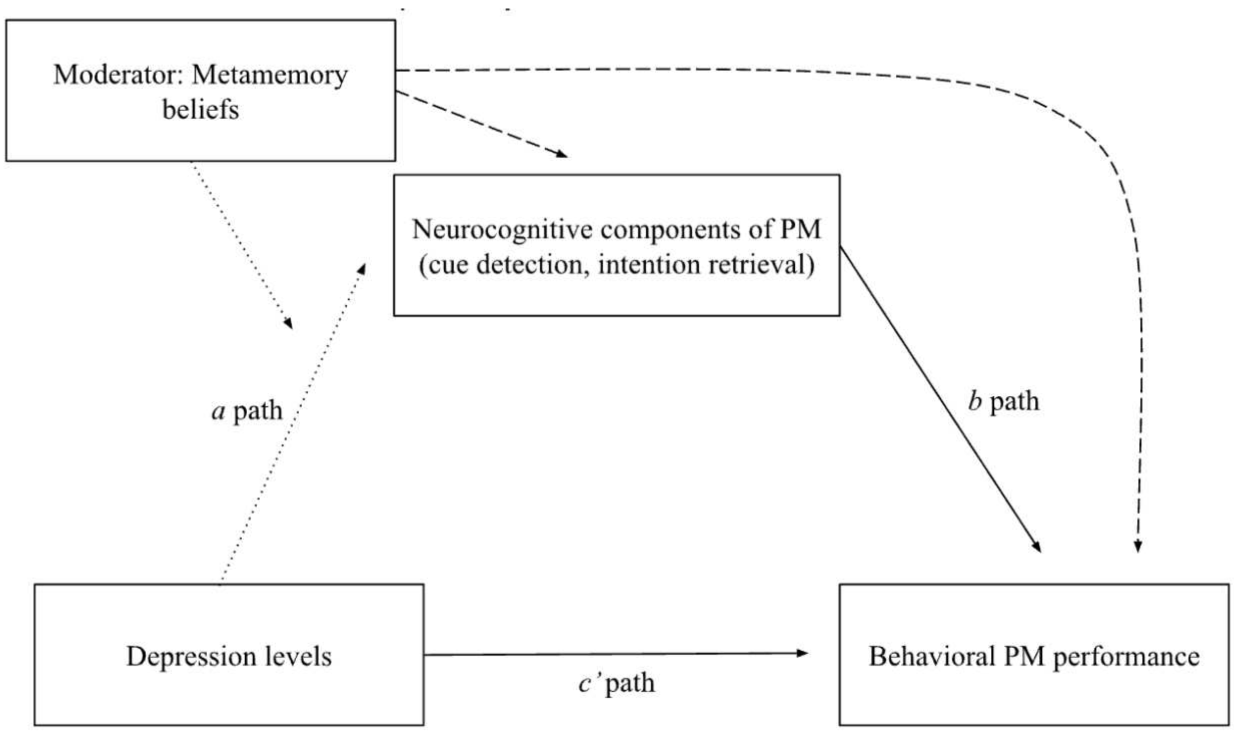



*Figure 1*. Model Example Relating Depression to PM Performance via the ERP Components of PM with Metamemory Beliefs as the Moderator. The relationship between metamemory beliefs and the ERP components of PM will be assessed in Study 1, represented by the dashed line. Study 1 will also examine the relationship between metamemory beliefs and behavioral PM performance. The interaction between depression and metamemory beliefs on the ERP components of PM will be assessed in Study 2, represented by the dotted lines. The presence of an interaction effect could support a moderated effect for Study 3. The mediation model (*a* path, *b* path, *ab*, *c*' path) and moderated mediation will be assessed in Study 3. The moderated mediation is represented by the role of the moderator (metamemory beliefs) on the *a* path of the mediation model.

# CHAPTER 2: NEURAL CORRELATES OF METAMEMORY FOR PROSPECTIVE MEMORY

## 2.1. SUMMARY

Study 1 examined how metamemory beliefs relate to prospective memory (PM) performance and its underlying neurocognitive mechanisms, specifically cue detection and intention retrieval as assessed via electroencephalogram/event-related potentials (EEG/ERPs). Eighty college students completed metamemory assessments and a computerized, event-based PM task while the N300 and prospective positivity ERP components were recorded. Findings indicated that higher self-reported PM confidence, as assessed by the Prospective and Retrospective Memory Questionnaire (PRMQ), was associated with greater PM behavioral accuracy and stronger intention retrieval responses, as reflected by increased prospective positivity amplitudes. Differences in the N300, representing cue detection, were not significantly predicted by the metamemory measures. Participants' general confidence in cognitive abilities and specific performance predictions did not significantly relate to PM accuracy but were associated with faster response times. These findings suggest that confidence in PM ability may be critical for optimizing cognitive resource allocation and enhancing PM performance, specifically for intention retrieval. This research highlights the importance of metamemory beliefs in PM tasks, providing insights that may support college students in improving future-oriented goal-directed behaviors by encouraging positive self-assessments of PM skills.

## 2.2. INTRODUCTION

### Prospective Memory

Prospective memory (PM) allows the successful execution of future-intended goals, and it is a critical cognitive process for various real-world tasks (Einstein & McDaniel, 1990; 2005). For example, PM is employed when completing and submitting assignments for work and school, making plans to attend a movie with a friend, and preparing food to make a meal (Einstein & McDaniel, 2005). If the intended goal is cued by an event, it is categorized as an event-based PM task. If the intended goal is cued by a particular time, it is categorized as a time-based PM task (Cona et al., 2012). Researchers have theorized that event-based PM requires more cognitive resources than time-based PM, due to the unpredictable nature and spontaneity of event-based PM (Cona et al., 2012). Based on this concept, event-based PM will be the focus of the current project. PM is comprised of two components: cue detection and intention retrieval. Cue detection (i.e., the prospective component of PM) describes the moment an individual notices the cue to carry out their future oriented goal. Intention retrieval (i.e., the retrospective component of PM) follows cue detection and characterizes the act of an individual recalling and performing their future oriented goal (Einstein & McDaniel, 1990; 2005).

#### *Prospective Memory and Event-Related Potentials*

In this study, event-related potential (ERPs) will be used to expand upon existing behavioral studies examining the relationship between behavioral PM and metacognition. Previous literature has demonstrated that cue detection and intention retrieval can be characterized through two ERP components: the N300 and the prospective positivity (West & Krompinger, 2005). The N300 is identified by brief negativity over the occipital–parietal region between 200 and 400 ms after stimulus presentation (West et al., 2001). The N300 is likely involved in cue detection, as the amplitude of the N300 increases in negativity for correct PM responses in comparison to incorrect PM responses (West et al., 2003; West & Ross-Munroe, 2002). The prospective positivity is distinguished by long-lasting positivity over the parietal region between 500 and 1000 ms after stimulus presentation (West et al., 2001). The prospective positivity is implicated in intention retrieval, as the amplitude of the prospective positivity increases when there are multiple intended actions associated with a cue, compared to when there is one intended action associated with a cue (West & Ross-Munroe, 2002).

### ***Importance of Prospective Memory***

While PM is an important skill for all populations, the demands of college require a particularly high level of this cognitive function for students. College students must juggle a number of immediate and long-term goals including succeeding in their classes and jobs, maintaining their physical, emotional, and mental health, and balancing their social life. The behaviors required to complete these goals include attending class and meetings, completing and submitting assignments, consistently studying, attending important appointments, following through on retrieving prescriptions, taking medication at appropriate times, grocery shopping and preparing meals when necessary, and making time for friends and social events. These behaviors contribute to academic success (Horton & Snyder, 2009), and emotional, cognitive, and physical health (Burrows et al., 2017; Miller et al., 2008). To succeed in these domains, students must be able to set and maintain future intentions, manage their time so that they are able to complete their goals, and notice when it is necessary for them to carry out their plans (Macan et al., 2010). Healthy PM abilities allow students to guide and direct their time management skills, daily habits, and priorities to complete their long-term goals (Macan et al., 2010).

If a student experiences a failure of PM, they will likely undergo impairments in the behaviors that contribute to their academic and personal well-being. For example, if a student cannot efficiently perform the PM goal of completing and submitting a homework assignment on time, they will struggle to be successful in their classes. When PM issues are left unaddressed, these detriments can lead to negative outcomes for college students regarding their long-term goals and health. To promote the cognitive well-being and success of college students, it is critical for researchers to thoroughly examine factors that could be related to PM performance, including the various types of cognition that contribute to PM.

### *Prospective Memory and Its Related Cognitive States*

PM is related to various other forms of cognition including retrospective memory, attention, working memory, spontaneous retrieval, and metacognition. While retrospective memory is an important part of PM, demonstrated by the retrospective intention retrieval component, there are important distinctions between these two types of memory. PM requires an individual to remember a specific prompt to carry out the target task, which is not the case in retrospective memory alone (Einstein & McDaniel, 1990, 2005; McDaniel & Einstein, 1992). Retrospective memory behavioral tasks involve a researcher explicitly indicating to the participant when it is time for them to carry out the assigned task. On the other hand, PM tasks ask participants to stop engagement in an ongoing task to perform the future-intentioned goal, which could be signaled by a word, object, event, or timeframe in the ongoing task. They are responsible for recognizing this signal on their own (i.e., cue detection) and remembering the future-intentioned goal (i.e., intention retrieval), requiring them to maintain memory of both the appropriate cue and the intended action (Einstein & McDaniel, 1990; 2005; McDaniel &

Einstein, 1992). While retrospective memory is involved in PM tasks and goal completion, PM requires more self-initiative processes than retrospective memory (Craik, 1986).

Further, attention and working memory are also important factors in PM abilities (Anderson et al., 2017; Einstein et al., 1997; Smith, 2003; Smith et al., 2007). Attention allows an individual to be able to focus and guide their cognitive abilities to their environment, ultimately supporting cue detection (Smith et al., 2007). Working memory also enables and supports PM performance, as an individual would employ their working memory capacity to maintain the appropriate cue and/or goal in their mind while monitoring their environment (Einstein & McDaniel, 2005). PM is a multifaceted and dynamic cognitive ability that relies on the interplay of retrospective memory, attentional processes, and working memory capacity to support cue detection and intention retrieval.

Metacognition and its related form of cognition, metamemory, also play important roles in PM performance, as metacognitive and metamemory abilities relate to how people decide to implement memory strategies, reminders, and coping mechanisms based on their positive and negative beliefs of their cognitive and memory skills (Meeks et al., 2007). Metacognition and metamemory are unique from the other forms of cognition involved in PM, as individuals can use the former abilities to evaluate their predicted PM performance; based on this evaluation, they can decide whether they need to give more effort towards attending to the environment for the cue or not, maintaining the intended cue and task in their mind, or implementing the use of tools to support their PM abilities (Kliegel et al., 2008). Due to the evaluative role of metacognition and metamemory, these forms of cognition are particularly interesting to assess when examining factors that could play a role in overall PM performance. To assess potential elements that could impact everyday PM performance, the current study focuses on the role of metacognition in PM.

## Metacognition and Metamemory

Metacognition is a broad term used to describe the ability to observe, direct, and regulate one's own cognition (Flavell, 1979). Metacognitive abilities can be broken down to two levels: object level and metalevel (Nelson, 1990). The object level is the intended cognitive task, while the metalevel is the evaluation of task performance. Through judgements made at the metalevel, an individual can regulate and adjust their cognition at the object level (Nelson, 1990). In application, metacognition is commonly employed when a student is studying for an exam. For example, a student could be attempting to understand and memorize material (i.e., the object level). At the metalevel, the student would evaluate their ability to successfully encode the material. Based on their metalevel judgement, they would decide whether to continue their studying (Soderstrom et al., 2011). Metacognitive principles have also been applied to memory, termed metamemory. Metamemory refers to the understanding and beliefs an individual has about their own memory processes and abilities (Soderstrom et al., 2011). Metacognition and metamemory can be applied to PM, as one's beliefs about their memory and cognitive abilities may influence how they implement reminders or strategies to complete their future oriented goals (Huber et al., 2022).

### *Metacognition related to Prospective Memory*

To further understand the relevance of metacognition and metamemory in performing PM tasks, researchers have explored this relationship using Judgements of Learning (JOLs), behavioral performance predictions, and self-assessed memory questionnaires. Meeks et al. (2007) examined correlations between self-performance predictions on a PM task, accuracy on the PM task, and self-report levels of daily PM performance via the Prospective and Retrospective Memory Questionnaire (PRMQ). The results demonstrated that participants generally underestimated their PM performance when making a prediction about their performance, and there was a positive correlation between predictions and performance (Meeks et al., 2007). There was a negative correlation between daily PM errors reported on the PRMQ and PM performance predictions, indicating that participants who reported more daily PM errors on the PRMQ were more likely to also predict lower performance on the PM task. Meeks et al. (2007) suggest that participants have some level awareness of their PM abilities, although it is common to underestimate one's own abilities (Meeks et al., 2007).

Schnitzspahn et al. (2011) carried out a similar study, in which participants provided JOL assessments of their confidence to perform a behavioral PM task. More specifically, participants gave JOLs for the separate components of PM by both identifying a cue (i.e., cue detection) and carrying out the appropriate task (i.e., intention retrieval). The study found that delayed JOLs for both components were positively correlated with PM performance, although the immediate JOLs demonstrated no significant correlations. Interestingly, the results suggest that there were greater levels of under-confidence for the intention retrieval component than there were for the cue detection component, with a general pattern of under-confidence in PM performance overall (Schnitzspahn et al., 2011). While this study asked participants about judgments of the two components that comprise PM, no study has used neurophysiology to examine the relationship between metacognitive abilities and the neurocognitive PM components. Although some researchers have reported overconfidence in predicting PM abilities (Devolder et al., 1990), most literature seems to agree that adults are under-confident in their PM performance, and that their metacognitive beliefs at least partially predict their behavioral PM performance (Knight et al., 2005; Meeks et al., 2007; Schnitzspahn et al., 2011).

Ikeda (2010) specifically assessed metamemory using the PRMQ. This study demonstrated that participants with high metamemory beliefs of their PM abilities tended to perform better on a laboratory PM task than participants with low metamemory beliefs (Ikeda, 2010). While the relationship between PM and metacognitive abilities has not been widely studied, the PRMQ is a particularly useful measure of metamemory and metacognition (Smith, 2016). The PRMQ was created to assess self-reported perceptions of PM abilities, while other metacognitive measures may assess performance predictions, broader JOLs, and more general concepts of memory (Crawford et al., 2003; Da Silva Coelho et al., 2023). Kliegel and Jäger (2006) describe the utility and validity of the PRMQ as a metacognitive measure, as the PM subscale predicted PM performance and was cross validated with another metamemory measure, the Metamemory in Adulthood Questionnaire. Various broader metacognitive measures have been used to study metacognition related to PM, including the Cognitive Confidence subscale of the Metacognition Subscale (MCQ-30) and the Memory Self-Efficacy Questionnaire (MSE; Swain et al., 2023; Da Silva Coelho, et al., 2023). While the precise measure used to study metacognition and metamemory related to PM varies, a connection between the two is consistently observed across the literature. In summary, the literature primarily agrees that individuals tend to underestimate their PM abilities, and their predictions and judgements of their memory abilities positively relate to their PM performance. Further, while metacognition and metamemory can be difficult to examine, performance predictions and self-reported memory confidence assessments, particularly the PRMQ, are relevant and appropriate measures of metacognition related to PM.

### *Metacognition and ERPs*

Previous research has also investigated the neural correlates of metacognitive abilities. Participants have demonstrated a positive sustained waveform over the medial frontal areas, and a negative sustained waveform over the occipital areas, 350 ms to 700 ms following the cue to make a JOL during a learning paradigm (Müller et al., 2016; Skavhaug et al., 2010; 2013). While there are no existing studies on the neural correlates of metacognition related to PM, the current literature demonstrates the utility of ERPs in examining the neural underpinnings of metacognition. Instead of recording ERPs while the participants make metacognitive judgements, the present study will expand the field by investigating how metacognition for PM predicts the ERPs for PM, specifically for the N300 and the prospective positivity components. These results could provide information as to how beliefs of one's own memory abilities relate to cue detection and intention retrieval, which could ultimately contribute to how somebody chooses to implement memory reminders and allocate their cognitive resources.

### *Importance of Metacognition*

Metacognitive abilities have important implications for carrying out real-world behaviors and goals. Previous research has demonstrated that metacognition can guide study habits and self-regulation, ultimately predicting academic achievement (Schneider, 2008; Zimmerman, 1986). As an individual makes judgments and assessments of their cognitive abilities, they will likely use these assessments to make decisions regarding effort, time management, encoding, and goal-related behaviors. Regarding PM, metacognitive and metamemory judgements allow individuals to direct their attention and cognitive effort towards monitoring the environment for a cue, setting an intended goal, and retrieving the intended goal from their memory (Kliegel et al., 2008). If an individual is more accurate in their metacognition towards PM, they will be more successful in utilizing appropriate strategies to carry out and perform their PM goal (Meeks et al., 2007). For example, if a student believes they will be able to easily remember to submit an assignment on time (i.e., PM goal), they may not implement reminder strategies to support their goal. If this student has inaccurate metacognitive judgement and is incorrect about their memory abilities, they may not complete and submit their assignment on time, diminishing their academic achievement. Based on the importance of PM in college students, examining the role that metacognition may play in goal setting abilities has the potential to support the success, health, and well-being of students.

## Statement of Purpose

The purpose of the current study is to examine metacognitive/metamemory beliefs for behavioral PM in college students, as well as the neural correlates of PM associated with metacognitive/metamemory beliefs. By examining metamemory abilities related to behavioral PM for college students, researchers can determine if students' memory beliefs are accurate representations of their PM performance, and if their metamemory beliefs predict their PM performance. Incorporating EEG/ERPs allows the study to determine if metamemory has a particular relationship with either neurocognitive component of PM (i.e., cue detection or intention retrieval). With this information, researchers can advise college students on how to think about their own memory abilities, implement memory strategies, and carry out their intended goals. For example, if the study finds that metamemory scores positively predict the amplitude of the prospective positivity (i.e., intention retrieval) but not the N300 (i.e., cue detection), it is possible that beliefs about one's memory could be specifically related to their ability to recall their intended goal. Based on this data, the results would suggest that students should be given strategies to improve their memory self-judgements, which would ultimately support their intention retrieval abilities, and behavioral PM performance. To the author's knowledge, this is the first study that will utilize EEG/ERPs when investigating metamemory, behavioral PM, and the neurocognitive components of PM in college students.

**Hypothesis 1**

Based on the previous studies demonstrating that people's predictions of their PM performance positively correlate with their actual PM performance (Meeks et al., 2007; Schnitzspahn et al., 2011; Ikeda et al., 2010), I hypothesize that more negative subjective metamemory ratings, memory confidence, and memory predictions, assessed using the PM subscale of the PRMQ, the Cognitive Confidence subscale of the MCQ-30, and predictions for task performance, will predict reduced behavioral PM performance.

**Hypothesis 2**

Schnitzspahn et al. (2011) suggested that intention retrieval may be more sensitive to metamemory predictions than cue detection. Based on these findings, I hypothesize that negative metamemory beliefs measured from the PM subscale of the PRMQ, the Cognitive Confidence subscale of the Metacognition Questionnaire, and predictions for task performance will predict a lower prospective positivity amplitude.

See Figure 1 for a conceptual model of the proposed hypotheses. Overall, these behavioral and neural analyses will indicate the degree to which metamemory is related to PM performance, as well as the relationship between metamemory beliefs and the components of PM. With this data, the present study will be able to explore the role of metamemory in predicting the components of PM, and overall PM performance.

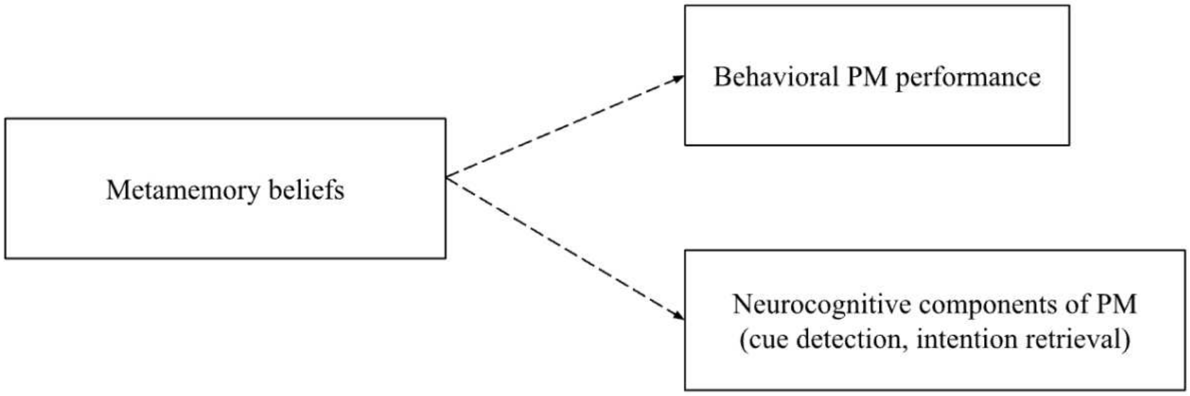



*Figure 1*. Model Relating Metamemory Beliefs to the Neurocognitive Components of PM and Behavioral PM Performance. The relationship between metamemory beliefs and the components of PM will be assessed in Study 1. Study 1 will also examine the relationship between metamemory beliefs and behavioral PM performance.

## 2.3. METHODS

### Participants

Data for this study were collected from the Department of Psychology undergraduate students at Colorado State University in 2023 and 2024. A power analysis was conducted using G*Power to determine the sample size required to detect small effect sizes in a fixed model regression analysis with a total of four predictors, including main effects and covariates (Faul et al., 2007). With a desired power level of 0.80 and an alpha level of 0.05, the analysis indicated that a sample size of 65 participants would be sufficient to adequately detect small effect sizes. We aimed to collect data from 80 participants to ensure sufficient power. Prior to coming to the lab, potential participants completed a demographics survey assessing biological sex, gender, age, race, ethnicity, socioeconomic status, handedness, and history of epilepsy. Exclusion criteria included being below the age of 18, not having normal or corrected hearing and vision, and a history of seizures. Corrected hearing and vision were necessary for participants to receive the instructions and carry out the task. Individuals with a history of epilepsy were excluded due to the irregularity in neural electrical activity associated with seizures, which could lead to irregular EEG readings. The other measures in the survey were not used to exclude participants, instead reported to fully convey the demographic characteristics of the sample.

Ninety-two participants completed the study. Twelve participants were excluded due to not understanding the task, with an accuracy lower than 10% on the PM trials. With these exclusions, there was final *n* of eighty ($M_{age}$=19.45, $SD_{age}$=2.75, 3 left-handed, gender identity: 56 women, 4 gender fluid individuals, 1 transgender woman, 3 transgender men). See Table 1 for the full demographics of the sample.

## General Procedure

Participants were consented and then completed the following surveys: the Prospective and Retrospective Memory Questionnaire (PRMQ; Smith et al., 2000), and the Cognitive Confidence Subscale of the Metacognition Questionnaire (MCQ-30; Cartwright-Hatton & Wells, 1997). The PRMQ was utilized due to previous studies successfully using the survey to assess metamemory for PM (Kliegel & Jager, 2006; Smith et al., 2011). The MCQ-30 Cognitive Confidence subscale was used based on previous research implementing this survey to measure more general metamemory beliefs with a PM task (Swain et al., 2023).

Following completion of the surveys, the participants were fitted with an EEG cap and provided with task instructions to complete the PM task. Once the participants received the instructions of the task and were given the opportunity to ask questions, they provided the researcher with a performance prediction (i.e., JOL), on a scale from 0% - 100%, for the PM task. This performance prediction was used based on a previous study examining metacognitive abilities and PM performance (Meeks et al., 2007). Upon completion of the task, participants were debriefed and participation in the experiment was documented for course credit/extra credit.

### ***Measures***

Prospective and Retrospective Memory Questionnaire (PRMQ; Smith et al., 2000): Participants reported subjective ratings of prospective and retrospective memory failures by indicating “Very often”, “Quite Often”, “Sometimes”, “Rarely”, or “Never” to how frequently they believe they experience various types of memory failures (e.g., “Do you decide to do something in a few minutes’ time and then forget to do it?”, “Do you fail to recognize a place you have visited before?”, “Do you fail to do something you were supposed to do a few minutes later even though it's there in front of you, like take a pill or turn off the kettle?"). This measure has high internal consistency ($\alpha$ = .89; Crawford et al., 2003). Metamemory of PM performance was quantified as a single continuous variable from adding the item responses of the PM subscale of the PRMQ. A higher score indicated increased reports of perceived memory problems. See Appendix A for a reproduction of the measure.

Cognitive Confidence Subscale of the Metacognitions Questionnaire (MCQ-30; Cartwright-Hatton & Wells, 1997): Participants reported confidence in their memory abilities by indicating, "1= Do not agree", "2= Agree slightly", "3 = Agree moderately", "4=Agree very much" to a series of six statements (e.g., "I have a poor memory", "My memory can mislead me at times"). The cognitive confidence subscale has been shown to have good reliability ($\alpha$ = .85; Swain et al, 2023). Cognitive confidence was quantified as a single continuous variable from adding the item responses. Higher scores indicated lower cognitive confidence. See Appendix A for a reproduction of the measure.

Performance prediction for PM task (Meeks et al., 2007): The researcher explained the instructions for the PM task and allowed the participant to ask questions, and then read the following statement: "On a scale of 0% - 100%, how likely are you to correctly perform the task?" The researcher recorded the participant's response. The procedure was adapted from Meeks et al. (2007) and Soderstrom et al. (2011). Performance prediction for the PM task was quantified as a single continuous variable. A higher score indicated more confidence in one's memory abilities. See Appendix A for a reproduction of the measure.

Visual Search PM Task: This task was used to assess behavioral PM performance (i.e., accuracy and reaction time; RT), and the ERP components of PM (i.e., the N300 for cue detection and the prospective positivity for intention retrieval). The task was created using

PsychoPy3 Experiment Builder (v2021.2.3; Peirce et al., 2019) and was adapted from West and Wymbs (2004). It had three essential components: an ongoing visual search task, a cue detection component, and an intention retrieval component. During the ongoing visual search task, participants were shown a target letter in the center of the computer screen, followed by two test letters on the left and right sides of the display. If the target letter was present in the test letters, the participant pressed V with their left index finger. If the target letter was not present in the test letter, the participants pressed B with their right index finger. The PM components were introduced to the visual search task after the participants completed a block of the isolated visual search task. The letters D and M served as the cue detection components of the PM task. If the letters D or M were present in the test letters, the participants needed to remember to select N with their right middle finger. Remembering to select N when prompted with D or M was the intention retrieval component of the PM task. This PM paradigm has been validated in previous research to elicit the desired ERP components (West & Wymbs, 2004).

The task began with instructions for the visual search task, without the PM components: there was one practice block of 10 trials and one test block of 96 trials. The practice block without PM included five target-present trials and five target-absent trials. The test block without PM included 24 target-present trials shown on the left side, 24 target-present trials shown on the right side, and 48 target-absent trials.

The instructions for incorporating the PM task were shown, and the task was continued. The task included one practice block of 10 trials, and three test blocks of 168 trials each. The practice block included two prospective-cue trials, four target-present trials, and four target-absent trials. The test block included 36 target-present trials shown on the left side, 36 target-present trials shown on the right side, and 72 target absent trials, 12 prospective-cue trials shown on the left side, and 12 prospective cue-trials on the right side. For prospective-cue trials, a non-target letter was presented in the display opposite the cue. The prospective cue and target were never presented together in a trial. The task ended with another test block of 96 trials for the visual search task without the PM component.

In the task, each trial included a target, a fixation, and a rest period. For the target display, the target letter was presented in the center of the computer monitor for 150 ms. The target was replaced by a fixation cross for 850 ms, followed by the test display. The test display included two letters presented on the left and right sides, with a fixation cross in the middle. The letters were presented in white, Arial font, 1/10 the size of the screen. They were separated by 35 mm of gray space. The test display was presented for 400 ms and then replaced by a blank gray screen until the response was made. If the participants did not respond after 5,000 ms, the task continued. The screen remained blank for 500 ms after the response, and then the target letter for the next trial was presented. For the first trial of each block, the screen was blank for 1,000 ms after the space bar was pressed to initiate the block (Rice et al., 2024; West & Wymbs, 2004). See Appendix B for a reproduction of the task stimulus and instructions.

PM performance was quantified as two continuous variables: accuracy and reaction time. Accuracy was calculated by averaging the number of correct prospective-cue trials. Reaction time was calculated by averaging the response times (ms) for the correct prospective-cue trials. Higher accuracy and lower reaction time suggest better PM performance.

**EEG Procedure**

Electroencephalography (EEG) was recorded at a rate of 1000 Hz using SynAmps2/RT 64 Channel system (Curry7, Compumedics NeuroScan, USA) (acquisition bandwidth = 1000 Hz, sampling rate = 1000 Hz) and a 64 electrode Quik-cap Neo Net with sewn-in or affixed to skin via an adhesive patch silver-chloride sintered electrodes (Diameter = 1.5 cm; Compudics USA, Inc. Model: C190). The electrodes were placed in the cap based on the 10-20 electrode placement standard. A .01 Hz high-pass filter and a 100 Hz low-pass filter was used during recordings. Electrode placements followed the Quik-cap 64 system and included all electrodes (Fpz, Fz, Pz, Poz, Oz, Fp1, Fp2, Af3, Af4, F1, F2 F3, F4, F5, F6 F7, F8, F11, F12, Fc1, Fcz, Fc2, Fc3, Fc4 Fc5, Fc6, Ft11, Fc12, C1, Cz, C2, C3, C4, C5, C6, T7, T8, Tp7, Tp8, Cp1, CPz, Cp2, Cp3, Cp4, Cp5, Cp6, P1, P2, P3, P4, P5, P7, P6, P8, Po3, Po4, O1, O2, Po7, Po8, Cb1, Cb2, left mastoid M1, right mastoid M2, VEOU, VEOL, HEOL, HEOR). Eye movements were monitored with electrode placement on positions lateral and superior of the left eye for Vertical Electrooculogram (EOG), and the outer corner of each eye for Horizontal EOG. The reference electrode was placed between Cz and CPz. The ground electrode was AFz. During recording, all electrodes were referenced to electrode Cz (Rice et al., 2024).

**EEG/ERP Analyses**

N300: Cue detection was calculated as a single continuous variable measured from the average amplitude (µV) of the neural responses for correct prospective-cue trials between 200 and 400 ms from electrodes O1, Oz and O2. A stronger negative amplitude indicated a stronger N300, suggesting an accentuated cue detection response (Chen et al., 2015; Rice et al., 2024; West & Wymbs, 2004).

Prospective positivity: Intention retrieval was calculated as a single continuous variable measured from the average amplitude (µV) of the neural responses for correct prospective-cue trials between 500 and 1000 ms from electrodes P3, Pz and P4. A stronger positive amplitude indicated an enhanced prospective positivity, suggesting a greater intention retrieval response (Chen et al., 2015; Rice et al., 2024; West & Wymbs, 2004).

EEG data were processed in MATLAB (version R2022b) using EEGLAB (version 2024.0) with the ERPLAB plug-in (version 10.04; Lopez-Calderon & Luck, 2014). A 0.1–30 Hz zero-phase-shift bandpass filter was applied. Ocular artifacts were corrected using the Independent Component Analysis feature in EEGLAB. The EEG data were re-referenced to an average reference and trials exceeding a voltage of +/- 100 µV were removed from trials. The ERP epoch included -200 to 1200 ms of activity around stimulus onset (Rice et al., 2024). To analyze the electrode clusters, mean voltages of electrodes O1, Oz, and O2 were averaged to measure the N300. Mean voltages of electrodes P3, Pz, and P4 were averaged to measure the prospective positivity, as has been performed in previous literature (Chen et al., 2015; Groot & Strien, 2019; Zhang et al., 2019).

**Statistical Methods**

Multiple linear regression analyses were conducted in R (version 4.3.1; R Core Team, 2021) to examine associations among metamemory beliefs reported from the PRMQ, Cognitive Confidence scale, performance predictions, prospective memory accuracy and reaction time, and the neurocognitive components, the N300 and the prospective positivity, with participant age and gender as control variables in the models. Gender and age were controlled for due to metamemory, PM performance, and ERPs varying with age and gender (Bowman et al., 2015; Guillem & Mograss, 2005; Hertzog et al., 2019; Riess et al., 2016; Schnitzspahn & Kliegel, 2009; West, 2011). Controlling these variables allowed the current study to isolate the role of metamemory on PM performance and the relevant ERPs, without the confounding influences of age and gender. Gender was categorized into three groups to account for individuals outside the gender binary (e.g., man, women, and transgender + nonbinary) and dummy coded for regression analyses (DuBois & Shattuck-Heidorn, 2021).

Effect sizes were measured using partial R-squared, calculated from the linear regressions. To obtain effect sizes, R-squared values were calculated for both the full models and reduced models (i.e., excluding the independent variable). Then, the partial R-squared was calculated as the difference between the R-squared values for the full and reduced models, capturing the unique effect size of the independent variables while controlling for age and gender. An exploratory paired samples *t*-test was run on the difference between performance predictions and observed accuracy to determine if there was a significant difference between predicted accuracy and observed accuracy. All tests were two tailed ($\alpha = .05$).

### *Missing Data*

There were no instances of missing data in the sample.

### *Interpretation of Analyses*

For all analyses, standardized betas and effect sizes were used to communicate the extent and strength of the relationships. While *p*-values were reported and used to determine significance, more emphasis will be placed on effect sizes and beta values. Significance testing via *p*-values indicates the likelihood that any findings are due to chance, but this form of analysis does not describe the magnitude of the findings and is more dependent on sample sizes (Sullivan & Feinn, 2012). Standardized betas and effect sizes provide critical information not described by *p*-values. For the regression models, standardized betas ($\beta$) provide information on the strength and direction of the relationships (van Ginkel, 2020). The effect size measure, partial R-squared ($\eta^2$), indicates the amount of variance in the dependent variables explained by the independent variables after controlling for covariates (Levine & Hullett, 2002; Stoffel et al., 2021). Partial R-squared values and standardized beta values less than .1 indicate a very small effect size, .1 to .3 suggest small effect sizes, .3 to .5 demonstrate medium effect sizes, and great than .5 indicate large effect sizes (Cohen, 1988). Due to the importance of standardized betas and effect sizes, the interpretation of the results does not focus on the *p*-values, although *p*-values for the analyses will be reported. When reporting *p*-values, a value of ($\alpha = 0.05$) indicates statistical significance, and a value of ($\alpha = 0.10$) indicates marginal significance.

## 2.4. RESULTS

### Descriptive Statistics

Descriptive statistics for metamemory measures, prospective memory performance, the N300, the prospective positivity, gender, and age, and zero-order correlations between these variables are provided in Table 2. Gender was correlated with metamemory assessed by the PRMQ ($p < .05$). Age was not correlated with any of the variables of interest. The main effects were tested without the covariates, and the results did not change in a meaningful way.

The range of the PRMQ is 8 to 40. A lower score suggests positive beliefs of PM abilities, while a higher score suggests negative beliefs. In this sample, the average PRMQ score was 24 with a range of 9 to 39 (see Table 1). This distribution indicates variation in PRMQ scores without a strong skew towards positive or negative PM beliefs.

The range of the Cognitive Confidence Scale is 6 to 24. A lower score suggests positive beliefs, while a higher score suggests negative beliefs. In this sample, the average Cognitive Confidence score was 12 with a range of 6 to 22 (see Table 1). This distribution indicates variation in Cognitive Confidence scores, with a slight skew towards more negative metacognitive beliefs.

The range of PM task performance prediction scale is 0% to 100%. A lower score indicates less confidence in task performance, while a higher score suggests more confidence in task performance. In this sample, the average performance prediction score was 71% with a range of 15% to 100% (see Table 1). This distribution indicates some variation in task performance predictions, although there was a stronger skew towards higher predictions, suggesting the sample generally had higher confidence in their task-specific performance.

**Main effects of Metamemory and Prospective Memory**

The results demonstrated a significant inverse association between PRMQ scores and PM accuracy ($\beta$ = -.33, $p$ < .01, $\eta^2$ = .100). See Figure 2. Cognitive Confidence and performance predictions were not significantly associated with PM accuracy ($\beta$ = -.16, $p$ = 0.182, $\eta^2$ = .023; $\beta$ = .17, $p$ = 0.148, $\eta^2$ = .027). There was a positive association between Cognitive Confidence and reaction time, and a negative association between performance predictions and reaction time ($\beta$ = .25, $p$ = 0.029, $\eta^2$ = .061; $\beta$ = -.34, $p$ < .01, $\eta^2$ = .113). See Figures 3 and 4. PRMQ was not significantly associated with reaction time ($\beta$ = .22, $p$ = .341, $\eta^2$ = .012). All analyses controlled for age and gender.

**Main effects of Metamemory and ERPs**

There was a significant inverse association between PRMQ scores and prospective positivity amplitudes ($\beta$ = -.29, p = 0.011, $\eta^2$ = .079). See Figure 5. Cognitive Confidence scores were significantly negatively associated with the prospective positivity at a trend level ($\beta$ = -.17, $p$ = .098, $\eta^2$ = .035). Performance predictions were not associated with the prospective positivity ($\beta$ = -.04, $p$ = .70, $\eta^2$ = .002). The PRMQ scores, Cognitive Confidence scores, and performance predictions were not significantly related to N300 amplitudes ($\beta$ = -.10, $p$ = .400, $\eta^2$ = .001; $\beta$ = .01, $p$ = .920, $\eta^2$ = .000; $\beta$ = -.13, $p$ = .280, $\eta^2$ = .015). See Figure 6. All analyses controlled for age and gender.

**Exploratory Analyses**

A paired samples *t*-test was run on the difference between performance predictions and observed accuracy. The average predicted performance score was 71.30% (*SD* = 17.36). The average observed accuracy was 73.09% (*SD* = 23.05). There was no significant difference between performance predictions and actual accuracy ($t$(79) = .61, $p$ = .546).

## 2.5. DISCUSSION

The current study examined the role of metamemory beliefs in predicting behavioral PM performance and the neurocognitive components of PM, cue detection and intention retrieval, as assessed by EEG/ERPs. The findings partially support the hypotheses: more positive metamemory beliefs for PM predicted better PM accuracy. While the Cognitive Confidence Scale and performance predictions were not significantly related to accuracy, higher cognitive confidence beliefs and increased performance predictions were associated with shorter response times. Further, more positive metamemory beliefs for PM abilities predicted a higher prospective positivity amplitude, suggesting a stronger intention retrieval response. Considering the PRMQ was the only metamemory measure related to both behavioral PM performance and its neurocognitive components, these findings suggest that beliefs of one's cognitive ability play an important role in actual PM performance and neural responses, especially regarding metamemory related to PM. See Figure 7 for a representative model of how metamemory beliefs for PM play a role in both PM accuracy and intention retrieval.

**Metamemory Related to Prospective Memory**

The findings of the current study align with previous literature on the relationship between metamemory and PM (Ikeda, 2010; Schnitzspahn et al., 2011; Meeks et al., 2007). Both reaction time and accuracy were predicted by the metamemory self-report measures, with more cognitive confidence and higher performance predictions related to faster reaction times, and more positive beliefs for PM abilities associated with increased PM accuracy. Interestingly, this study does not suggest that college students are underconfident in their PM abilities, as there was no significant relationship between their performance predictions and their observed accuracy. While this particular finding is not consistent with previous research demonstrating under-confidence in PM abilities for adults, this study still reveals an important relationship between metamemory and PM abilities (Schnitzspahn et al., 2011; Meeks et al., 2007). These results suggest that college students have somewhat accurate metacognitive awareness of their PM abilities, and their perceptions of their general cognitive skills and task-specific abilities may play a role in their behavioral responses and success for PM. This relationship could exist due to metamemory beliefs guiding how individuals choose to allocate their attention when performing a PM task.

Theories of metamemory describe metacognition as including both awareness of one's cognition and the ability to control one's cognitive abilities (Fiedler et al., 2019; Nelson, 1990). It is possible that students with more positive metamemory judgements (e.g., I have good memory skills, and I rarely forget my goals) have better control over their ability to allocate cognitive resources and attention towards task demands, while students who self-report more PM failures in their daily lives (e.g., I struggle to remember when and how to complete my goals) may have less control over their cognitive effort. Specifically related to PM, students with confident metamemory beliefs for PM may be able to effectively identify the appropriate goal-related heuristic cues necessary to successfully perform the task, as has been shown to be an important factor in metacognition positively predicting performance (Hoch et al., 2023; Rhodes, 2019). This study highlights the importance of understanding how one's beliefs of their abilities may play a critical role in their cognitive effort and behavioral performance. By better understanding this relationship, researchers can advise college students on the real-world implications of their self-evaluations and attentional resources.

**Metamemory's Relationship to Intention Retrieval**

Further, previous research has suggested that more confident metacognitive appraisals may be associated with increased cognitive allocation, as assessed using EEG markers for mental effort (Balconi et al., 2023). The current study supports this concept, as students who reported having successful PM performance in their daily lives demonstrated an enhanced prospective positivity response, suggesting that they were allocating more cognitive resources towards intention retrieval. This relationship was not seen for the Cognitive Confidence Scale or performance predictions, indicating that students with positive metamemory beliefs specifically for PM may be more sensitive to the demands involved in successful PM performance, but general metacognitive beliefs may not be as relevant for the neurocognitive underpinnings of PM. The relationship between the PRMQ and intention retrieval in the current study is also consistent with Schnitzspahn et al.'s (2011) findings that intention retrieval is more sensitive to metacognitive judgements than cue detection, although the present study did not include delayed JOLs as was seen in Schnitzspahn et al.'s (2011) study.

None of the metamemory measures were related to the N300, indicating metamemory assessments did not predict cue detection responses, only intention retrieval. This finding suggests that when allocating cognitive resources based on metamemory judgements, college students do not seem to vary their effort towards monitoring the environment for the cue (i.e., cue detection). In contrast, when students have positive metamemory beliefs for PM, they may be focusing more of their cognitive effort and resources towards maintaining and recalling the intended goal (i.e., intention retrieval). The effort placed towards intention retrieval could support PM performance, reflected by the increased accuracy and strengthened prospective positivity response from college students who reported positive metamemory beliefs for PM via the PRMQ. This work reflects critical nuances in the role of metamemory as a predictor for behavioral PM, cue detection, and intention retrieval, as this study specifies the importance of metamemory beliefs about PM as a predictor of observed PM accuracy and intention retrieval responses. By disentangling the complexities of these relationships, college students can be better equipped to successfully carry out their future-oriented goals.

Based on these findings, college students looking to enhance their goal-directed behaviors should focus on thinking more highly of their future-oriented memory abilities. Students who have negative beliefs of their PM skills could be educated of the importance of evaluating their abilities positively and believing that they can be successful in remembering to perform their goals. By informing students of manageable strategies to improve their PM performance, researchers can encourage them to see success as something within their control, possibly supporting more active engagement in cognitive skills required for PM (i.e., intention retrieval). Through aiming to have more positive beliefs about their ability to carry out plans, students could be primed to allocate their cognitive effort towards rehearsing and remembering their goal more effectively. As students practice rehearsing their intentions and experience improvements in PM, their confidence in their future-oriented memory abilities is likely to grow. This boost in confidence may further reinforce their willingness to focus effort on PM-relevant skills, supporting a cycle where rehearsal and confidence continually enhance PM performance. This tactic could support intention retrieval abilities and PM accuracy for college students, ultimately strengthening their goal-oriented skills and facilitating long-term success and wellbeing.

**Limitations**

While the findings of the current study support a crucial relationship between PM-related metamemory beliefs, PM performance, and intention retrieval, the results should be interpreted with regards to important limitations. The results are correlational in nature, as metamemory beliefs were not intentionally manipulated. Due to this lack of causation, we cannot be entirely confident in the directionality of the observed relationships. It is possible that decreased PM accuracy and a reduced intention retrieval response contribute to negative metamemory beliefs. While previous metacognitive experiments support a causal relationship consistent with the conceptual framework of the present study, suggesting that self-evaluations directly influence behavior, the methodology of this study did not allow a direct test of causality (Rhodes, 2019).

Another important limitation is the implementation of the metamemory measures before performance of the PM task. All participants responded to the metamemory questions before carrying out the task, which may have primed them to be more attentive to the task. For example, participants who rated themselves as having better memory skills may have been primed with confidence to put in more effort, while participants who rated themselves as having worse memory skills may have been inclined to put in less effort. Further, previous work suggests that drawing attention to the importance of a memory task can encourage participants to perform better (Murphy & Castel, 2021). While we did not explicitly state the importance of PM during the study, asking the participants about their PM skills before starting the task may have implicitly suggested importance. The task instructions emphasize the importance of all aspects of the task, but it could be important to vary when participant respond to the metamemory measures, or to assess how participants perceive the importance of the different components to prevent unintentional priming effects.

Further, the results of this study may suggest a speed-accuracy tradeoff, as none of the self-report measures demonstrated significance with both behavioral measures of PM performance, accuracy and reaction time (Heitz, 2014). Upon reviewing the literature, the speed-accuracy tradeoff phenomenon has not been discussed regarding PM, but it is still important to consider the limitations of assessing PM performance with a task that asks participants to respond both as accurately and quickly as possible. It is possible that different cognitive and psychological experiences contribute to some participants prioritizing speed over accuracy, and vice versa. While an examination of how metamemory may contribute to the speed-accuracy tradeoff for PM performance is outside the scope of the current study, continuing research should investigate these relationships. This pattern of results may have important implications in understanding the allocation of cognitive resources, behavioral decision making, and internal goals (Heitz, 2014). Alternatively, to reduce the speed-accuracy tradeoff, future PM studies could employ tasks that assess PM performance by either accuracy or reaction time, as opposed to both.

Related to the considerations of the PM task for this study, it is important to note that this study only examined event-based, focal PM skills, limiting the application of these results to other types of PM. Due to the focality of the task, it may have recruited less monitoring resources for the PM cue compared to a non-focal task, which could slightly limit the assessment of cue detection responses (Cona et al., 2014; Zuber & Kliegel, 2020). This task is supported by previous research to be an appropriate measure of PM, but future work should address these issues by implementing a non-focal task (e.g., select a specific key when a different color letter appears on the screen). Further, although a computerized PM task was essential for capturing the relevant ERP components, its design may not accurately reflect the prospective memory goals college students encounter in their real-world goals.

Finally, the sample for this study lacked comparable racial, ethnic, socioeconomic status, and gender diversity. Race and gender are social constructs that can shape individuals' unique life experiences, including encounters with discrimination, social segregation, and varying access to resources (Roberts et al., 2020). These differing experiences may influence psychological phenomena such as memory, executive function, neural activity, and mental health (Cavanaugh & Abu Hussein, 2020; Roberts et al., 2020; Short et al., 2013). Socioeconomic status is another important factor that can determine psychological well-being, brain development and ERPs (Moriguchi & Shinohara, 2019; Navarro-Carrillo et al., 2020; Perera-W. A. et al., 2021). Thus, the findings of this study may not be generalizable to individuals across all socioeconomic, racial, or gender identities. Future research should aim for a more balanced representation of participants from diverse racial, ethnic, financial, and gender groups.

**Future Directions and Conclusions**

Taken together, these findings are consistent with the growing field of metacognition and behavioral research, assessing how metamemory beliefs predict cognitive performance and success, and they further expand upon the literature by examining metamemory for PM and its neural associations. Importantly, all effect sizes for the significant relationships were small, suggesting there are likely other psychological and cognitive phenomena involved in PM performance and intention retrieval responses. Despite the small effect sizes, these findings reveal that beliefs of one’s PM abilities have real-world implications on performance and neural responses. College students with PM-related positive metamemory beliefs appear to be allocating more cognitive and neural resources towards intention retrieval, and they have enhanced PM accuracy.

These findings support previous literature that complex psychological and neurocognitive underpinnings are involved in successfully carrying out goals, as personal beliefs of one's memory performance may guide the neurocognitive factors that contribute to effective PM abilities, specifically intention retrieval. For college students looking to support their PM abilities, these findings suggest that they can successfully accomplish their goals by having more positive beliefs of their PM skills, which may support them in appropriately attending to the memory processes necessary to recall and perform their intended goal. With this strategy in mind, they would likely be able to more effectively accomplish future-oriented goals required to thrive in college, such as creating and carrying out study plans, and remembering to complete and submit assignments on time. By implementing elevated self-assessments of PM abilities, college students can enhance their overall PM performance, facilitating academic and personal success.

Future studies should expand upon this work by assessing how college students believe they are allocating their cognitive resources to complete their goals. Are students aware of how they may be focusing on their environment to detect when they should perform their future-oriented goal, or how they may be focusing on remembering what the goals is? Does this perception align with the results indicating that students with high metamemory beliefs allocate cognitive resources towards intention retrieval? Along these lines, future studies should examine whether educating students on the underlying neurocognitive factors necessary for effective PM skill alters how they allocate their cognitive effort. If students are aware of the importance of cue detection and intention retrieval in accomplishing their future-oriented goals, will they choose to attend to one aspect of PM over the other, or will they distribute their focus more equally? Finally, continuing work should experimentally confirm the current findings by manipulating feedback on participants' PM abilities, providing either positive or negative feedback, and assessing whether this feedback successfully enhances or impairs PM performance.

If researchers find that they are successful in strengthening PM abilities by educating students on the cognitive processes involved in accomplishing their goals, or by providing them with positive feedback on their cognitive skills, these findings could serve as potential intervention strategies for college students hoping to improve their PM performance. In conclusion, addressing students' beliefs of their PM skills could be a practical and useful approach for supporting intention retrieval and PM performance.

**TABLE 1**
*Descriptive statistics*

| Variable Name | *n* | Percent | Mean | Standard Deviation | Standard Error | Min. | Max. | Range |
|---|---|---|---|---|---|---|---|---|
| Age | - | - | 19.45 | 2.75 | .31 | 18 | 36 | 18 |
| Gender Identity | | | - | - | - | - | - | - |
| Man | 16 | 20.00 | | | | | | |
| Woman | 56 | 70.00 | | | | | | |
| Transgender Man | 3 | 3.75 | | | | | | |
| Transgender Woman | 1 | 1.25 | | | | | | |
| Gender Fluid | 4 | 5.00 | | | | | | |
| Race | | | - | - | - | - | - | - |
| White | 71 | 88.75 | | | | | | |
| Black or African American | 1 | 1.25 | | | | | | |
| Asian | 1 | 1.25 | | | | | | |
| Native American or Alaska Native | 1 | 1.25 | | | | | | |
| Native Hawaiian or Other Pacific Islander/White | 1 | 1.25 | | | | | | |
| Native American or Alaska Native/Black or African American | 1 | 1.75 | | | | | | |
| Do not wish to respond | 3 | 3.75 | | | | | | |
| Ethnicity | | | - | - | - | - | - | - |
| Not Hispanic of Latinx | 65 | 81.25 | | | | | | |
| Hispanic or Latinx | 14 | 17.5 | | | | | | |
| Do not wish to respond | 1 | 1.25 | | | | | | |
| Average Years of Parental Education (Socioeconomic Status) | - | - | 15.49 | 3.57 | .40 | 3 | 22 | 19 |
| PRMQ Score | - | - | 24.31 | 6.94 | .78 | 9 | 39 | 30 |
| Cognitive Confidence Score | - | - | 11.54 | 4.02 | .45 | 6 | 22 | 16 |
| Prediction Performance (%) | - | - | 71.30 | 17.36 | 1.94 | 15 | 100 | 85 |
| Accuracy | - | - | 73.09 | 23.05 | 2.58 | 11.11 | 98.61 | 87.50 |
| Reaction Time (ms) | - | - | 1005.5 | 274.52 | 30.69 | 282.68 | 2093.87 | 1811.19 |

**TABLE 2**

*Means, standard deviations, and correlations with confidence intervals*

| Variable | *N* | *M* | *SD* | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1. Accuracy | 80 | 73.09 | 23.05 | | | | | | | |
| 2. Reaction Time | 80 | 1005.50 | 274.52 | .08 | | | | | | |
| | | | | [-.14, .30] | | | | | | |
| 3. Prospective Positivity | 80 | 1.93 | 1.93 | .22* | .01 | | | | | |
| | | | | [.00, .42] | [-.21, .23] | | | | | |
| 4. N300 | 80 | 0.35 | 3.90 | .01 | -.01 | .39** | | | | |
| | | | | [-.21, .23] | [-.23, .21] | [.19, .56] | | | | |
| 5. PRMQ | 80 | 24.31 | 6.94 | -.31** | .08 | -.26* | -.07 | | | |
| | | | | [-.49, -.09] | [-.14, .30] | [-.45, -.04] | [-.28, .16] | | | |
| 6. Cognitive Confidence | 80 | 11.54 | 4.02 | -.15 | .23* | -.17 | .03 | .65** | | |
| | | | | [-.36, .07] | [.01, .43] | [-.37, .05] | [-.19, .25] | [.50, .76] | | |
| 7. Performance Prediction | 80 | 71.30 | 17.36 | .17 | -.33** | -.02 | -.13 | -.12 | -.10 | |
| | | | | [-.05, .37] | [-.51, -.12] | [-.24, .20] | [-.34, .10] | [-.33, .10] | [-.31, .12] | |
| 8. Age | 80 | 19.45 | 2.75 | -.02 | .06 | -.17 | -.03 | -.07 | -.09 | -.15 |
| | | | | [-.24, .20] | [-.17, .27] | [-.37, .05] | [-.25, .19] | [-.28, .15] | [-.30, .13] | [-.36, .07] |
| 9. Gender[1] | 72 | - | - | -.11 | -.12 | .11 | .06 | .17 | .20 | -.20 |
| | | | | [-.33, .12] | [-.34, .11] | [-.12, .33] | [-.18, .29] | [-.06, .39] | [-.04, .41] | [-.42, .03] |
| 10. Gender[2] | 64 | - | - | .13 | .05 | -.08 | .07 | .27* | .03 | .10 |
| | | | | [-.12, .36] | [-.20, .29] | [-.32, .17] | [-.18, .31] | [.03, .48] | [-.22, .27] | [-.15, .34] |
| 11. Gender[3] | 24 | - | - | .05 | -.08 | .00 | .16 | .47* | .29 | -.12 |
| | | | | [-.35, .44] | [-.47, .33] | [-.39, .41] | [-.26, .53] | [.09, .74] | [-.13, .62] | [-.50, .30] |

*Note. M* and *SD* are used to represent mean and standard deviation, respectively. Point-biserial correlation coefficients were calculated to assess the relationships between the binary categorical variable (gender) and the continuous variables. Pearson's correlation coefficients were calculated to evaluate the correlations between the continuous variables. Values in square brackets indicate the 95% confidence interval for each correlation. The confidence interval is a plausible range of population correlations that could have caused the sample correlation (Cumming, 2014). * indicates $p < .05$. ** indicates $p < .01$. Gender[1]: Man = 0, Woman = 1. Gender[2]: Women = 0, Transgender + nonbinary = 1. Gender[3]: Men = 0, Transgender + nonbinary = 1.

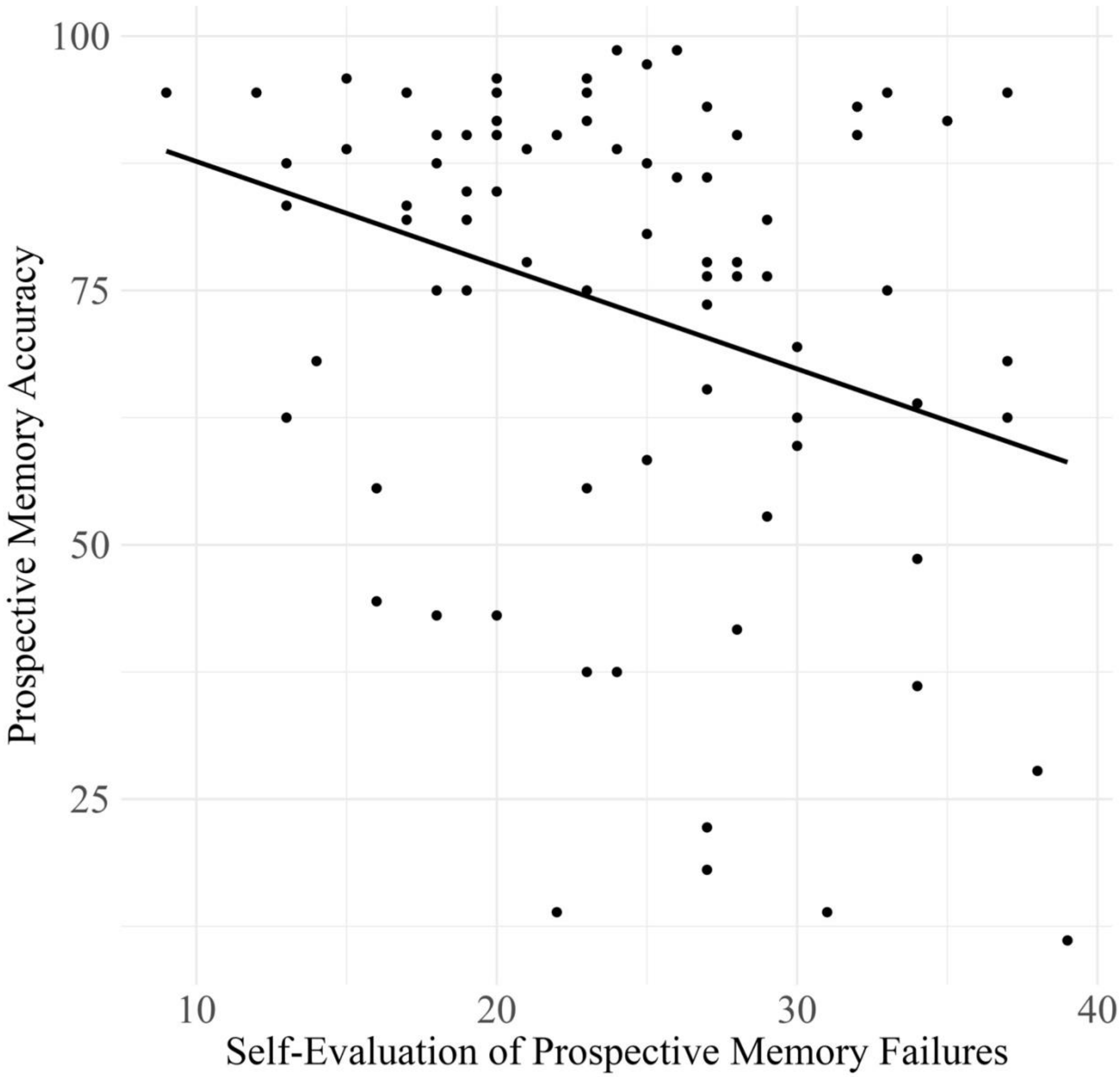



*Figure 2.* Results for Metamemory Related to Prospective Memory and Prospective Memory Accuracy. A scatterplot showing an increase in self-assessment of prospective memory failures, measured by the PRMQ, is associated with a decrease in prospective memory accuracy.

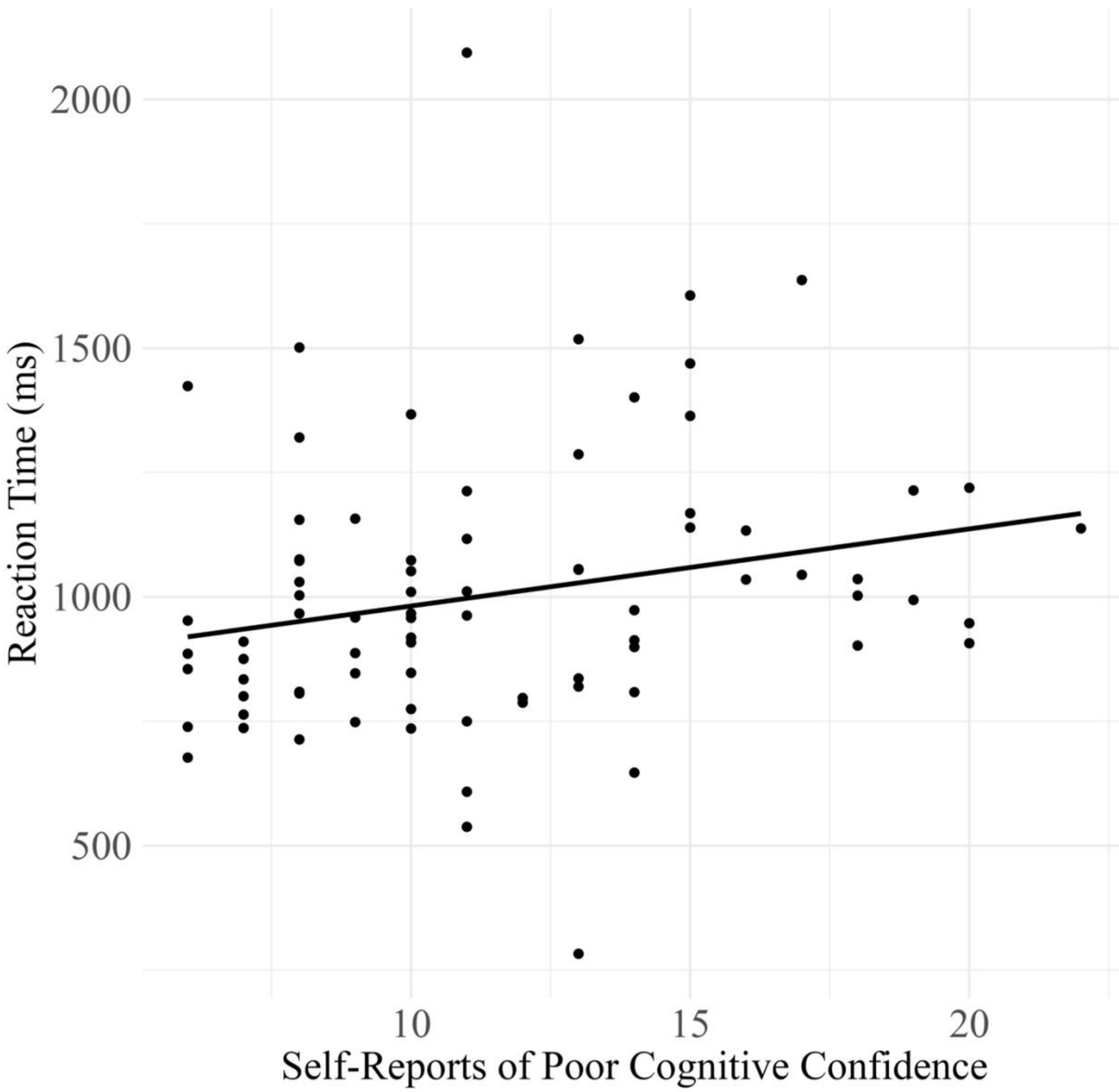



*Figure 3.* Results for Cognitive Confidence and Prospective Memory Reaction Time. A scatterplot showing an increase in reports of poor cognitive confidence, measured via the Cognitive Confidence scale, is associated with longer reaction times during the prospective memory task.

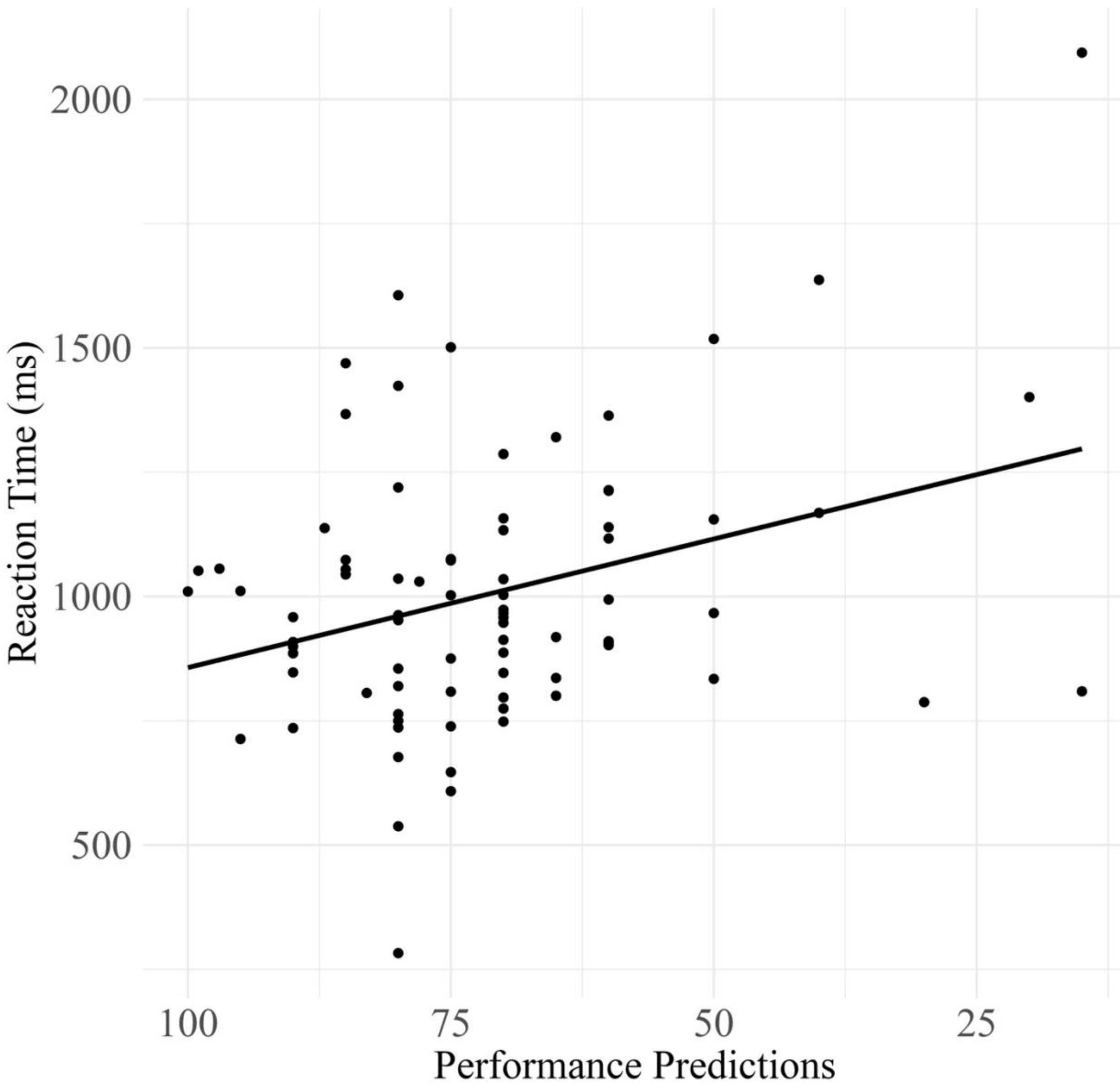
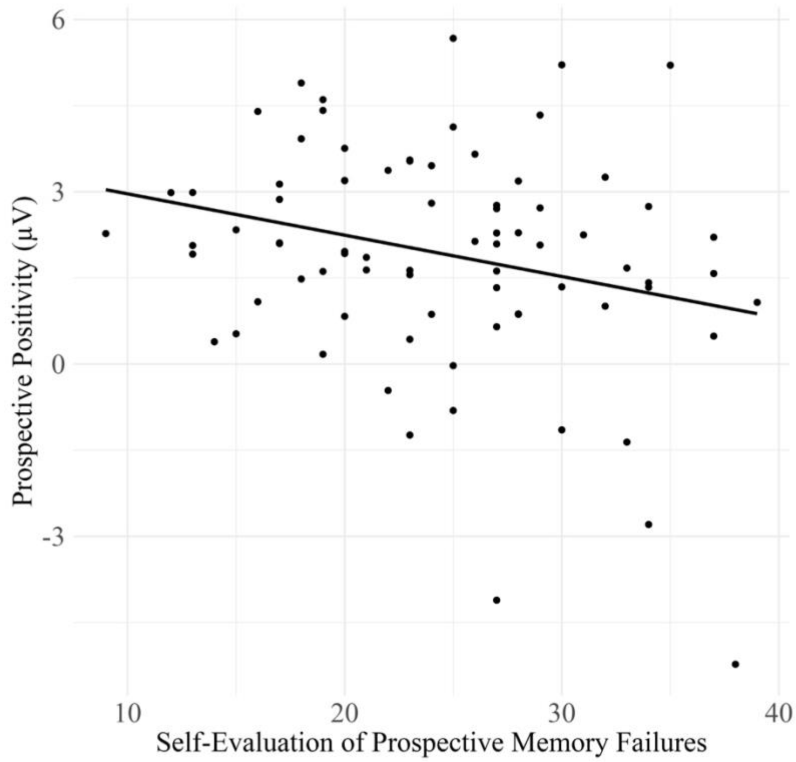


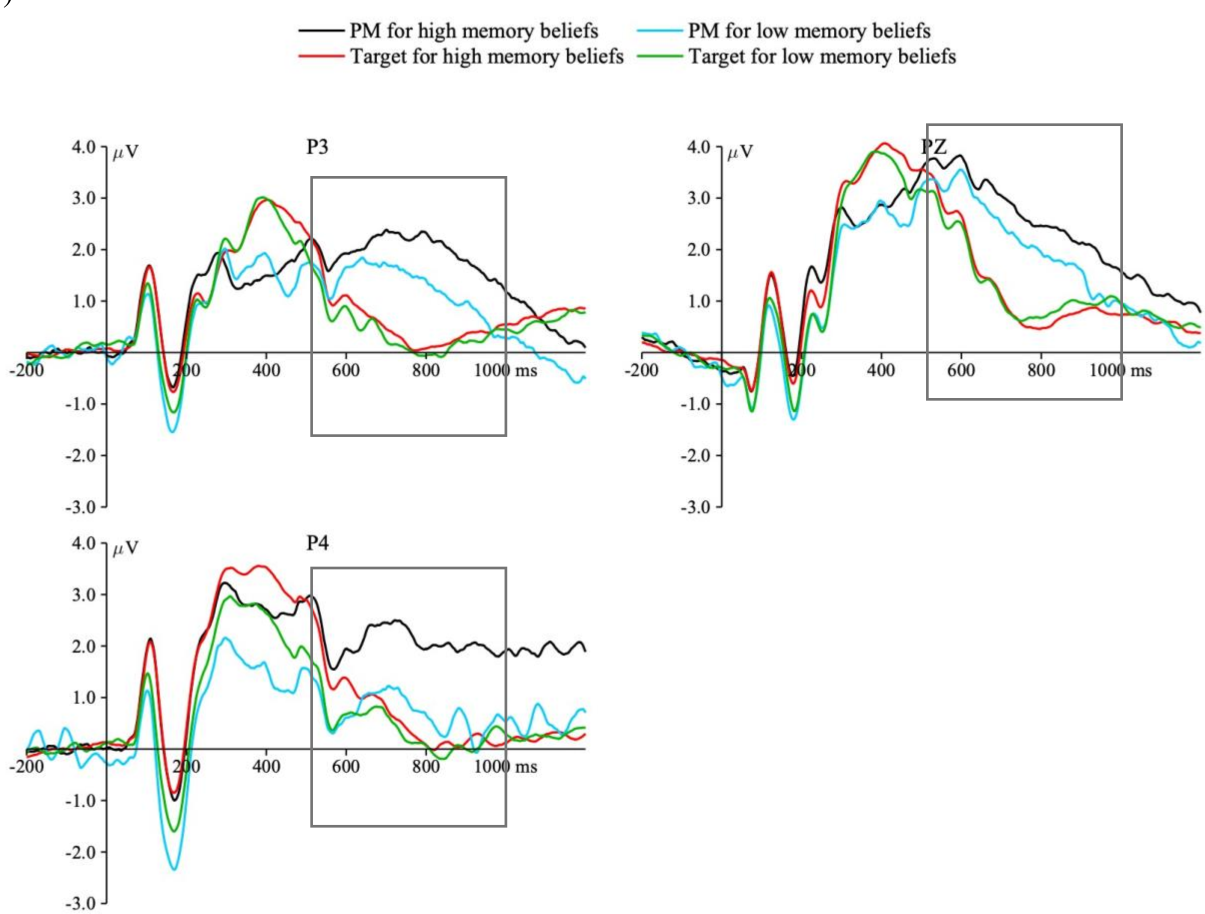

*Figure 4.* Results for Performance Predictions and Prospective Memory Reaction Time. A scatterplot showing an increase in performance prediction for the prospective memory task is associated with longer reaction times during the task.

A)



6
3
0
-3
10
20
30
40
Prospective Positivity (μV)
Self-Evaluation of Prospective Memory Failures


B)



PM for high memory beliefs
PM for low memory beliefs
Target for high memory beliefs
Target for low memory beliefs
P3
PZ
P4
μV
4.0
3.0
2.0
1.0
-1.0
-2.0
-3.0
-200
200
400
600
800
1000 ms

*Figure 5.* Results for Metamemory Related to Prospective Memory and Prospective Positivity Amplitude. A) A scatterplot showing an increase in self-assessment of prospective memory failures, measured via PRMQ, was associated with a decrease in prospective positivity amplitude. B) ERP results for the prospective positivity at electrodes P3, Pz, and P4. The prospective positivity is characterized by a sustained positive peak 500 – 1000 ms after stimulus onset. At all electrodes, the neural response during the PM trials for participants with high PM metamemory belief was stronger in comparison to the participants with low PM metamemory beliefs. This increased amplitude suggests a potential heightened response of the intention retrieval component for participants with more confidence prospective memory beliefs. The ERP graph is a useful visualization tool, but it is not intended to reflect group-based analyses for the relationship between metamemory and intention retrieval.

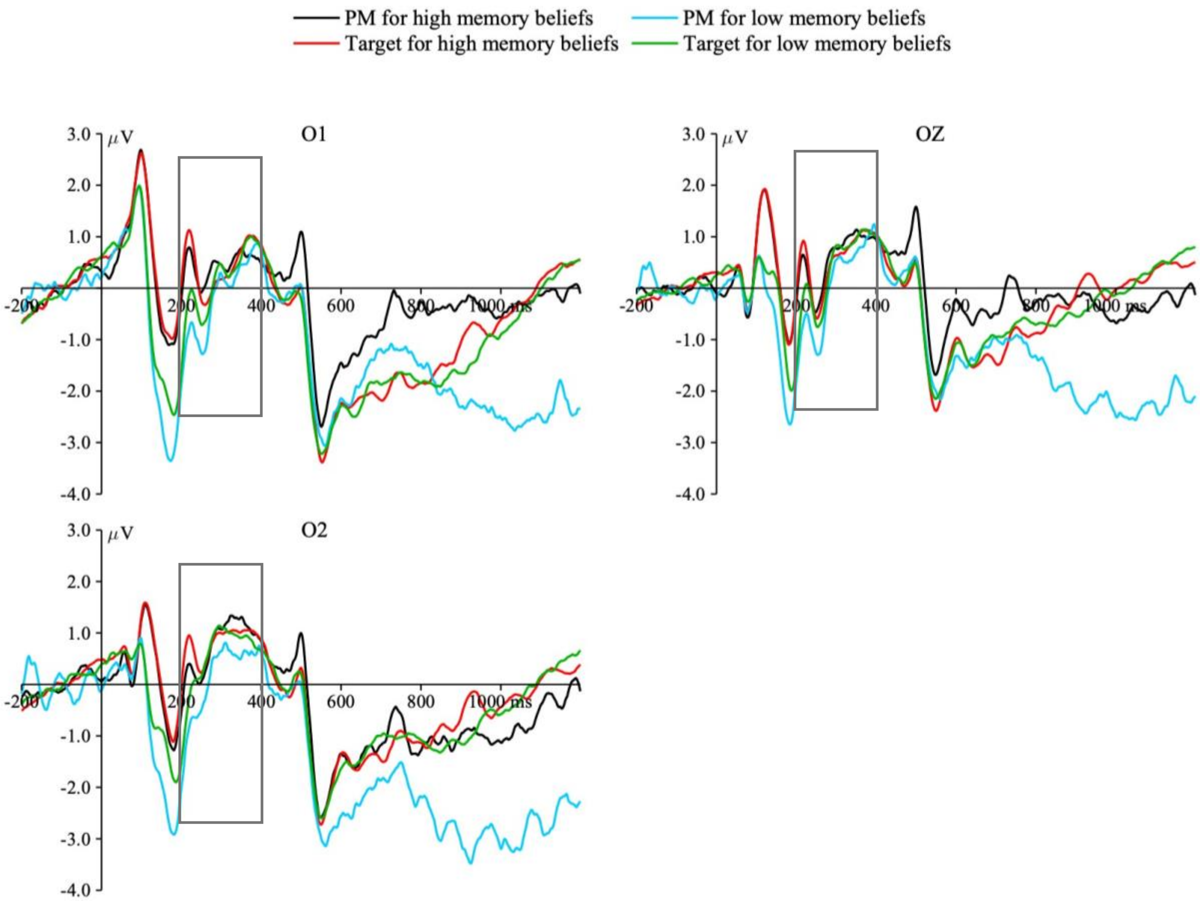



*Figure 6.* Results for Metamemory Related to N300 Amplitude. ERP results for the N300 at electrodes O1, Oz, and O2. The N300 is characterized by a brief negative peak, 200-400 ms after stimulus onset. There were no significant differences between N300 amplitudes for participants with reduced metamemory beliefs. The ERP graph is a useful visualization tool, but it is not intended to reflect group-based analyses for the relationship between metamemory and cue detection.

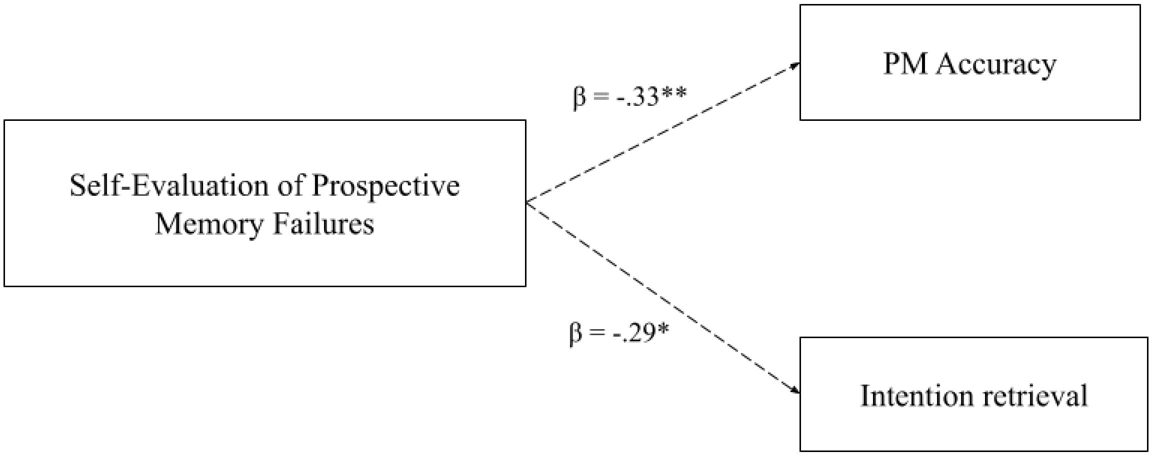



*Figure 7.* Model Results Relating Metamemory Beliefs for PM to Accuracy and Intention Retrieval Response. Increased reports of poor metamemory beliefs for PM, measured via the PRMQ, predicts worse PM accuracy and a reduced intention retrieval response. * indicates $p < .05$. ** indicates $p < .01$

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# CHAPTER 3: THE ROLE OF DEPRESSION AND METAMEMORY IN THE NEUROCOGNITIVE COMPONENTS OF PROSPECTIVE MEMORY

## 3.1. SUMMARY

Study 2 investigated relationships between depression, metamemory, and neurocognitive processes involved in prospective memory (PM) among college students. Eighty college students completed metamemory assessments and a computerized PM task while event-related potentials (ERPs) were recorded via electroencephalogram (EEG), with the N300 component representing cue detection, and the prospective positivity component characterizing intention retrieval. The results revealed significant associations between higher depression scores (on both PHQ-9 and CES-D) and negative metamemory beliefs in PM abilities, measured via Prospective and Retrospective Memory Questionnaire (PRMQ) and Cognitive Confidence scales. Depression did not directly predict prospective positivity or N300 responses. Interaction effects showed that worse (i.e., more negative) metamemory beliefs moderated the relationship between depression and N300 responses. For students with worse PM-self appraisals and reduced performance predictions, higher depression levels predicted a larger N300 response, suggesting heightened cognitive resources allocated to cue detection. No moderation was found with prospective positivity amplitude. These findings align with and expand upon previous studies indicating that depression may be related to changes in attention-related neural processes and cognitive efforts. This work suggests that targeted interventions to improve metamemory beliefs may help manage cognitive resource allocation in individuals with depression.

## 3.2. INTRODUCTION

### Depression and Metamemory

Depression is characterized by an inability to feel pleasure (i.e., anhedonia), feelings of worthlessness and sadness, exhaustion, and loss of interest in daily activities (Huber et al., 2022). It is the second most prevalent cause of disability globally, and depressive symptoms are an extremely common psychological experience among undergraduate college students (Kessler & Bromet, 2013). College students have reported depressive symptoms at a rate of 44% (Healthy Minds Network, 2023). Further, depression has been associated with impairments in various forms of cognition such as working memory, attention, executive functioning, and psychomotor speed (Andersson et al., 2010). Metacognition and its memory-related form, metamemory, may also be altered in individuals with depression (Sax et al., 2023). Metacognition describes how an individual perceives and predicts their own cognitive abilities, with memory the focus of metamemory (Da Silva Coelho et al., 2023; Flavell, 1979). While metacognition and metamemory could be impaired by depression, research has shown conflicting results.

One theory behind the relationship between metamemory and depression is referred to as the "sadder but wiser" phenomenon, which states that individuals with depressive symptoms may have more realistic expectations of potential cognitive impairments, resulting in more accurate metacognition and metamemory beliefs (Alloy & Abramson, 1979). Soderstrom et al. (2011) provided some support for this theory, as college students with mild depressive symptoms demonstrated more accurate metacognitive predictions than nondepressed students, although this pattern was not seen for moderately depressed students. This study suggests that some depressed individuals may have a more realistic view of their cognitive abilities, but this relationship does not exist for more extreme levels of depression.

Another line of research suggests that individuals with depression lack optimism and self-confidence, and they tend to underestimate their abilities, resulting in less accurate metacognitive and metamemory beliefs (Sax et al., 2023). In support of this idea, previous studies have demonstrated that individuals with increased depression report more negative metacognitive beliefs than their actual performance reflects in comparison to nondepressed participants (Fu et al., 2005; Moses-Payne et al., 2019; Rouault et al., 2018; Sax et al., 2023). Based on these competing frameworks, it is important for researchers to further examine the relationship between depression and metamemory abilities to better understand the potential cognitive toll of depressive symptoms.

**Metamemory for Prospective Memory**

Metamemory captures how an individual thinks about their own memory processes and abilities including future-oriented memory, also known as prospective memory (PM; Soderstrom et al., 2011). When applied to PM, metamemory may play a role in how an individual implements reminders or strategies to complete their future oriented goals (Huber et al., 2022). More specifically, if an individual has accurate metacognitive beliefs about their PM abilities, they will be more likely to appropriately use memory support strategies to perform their PM goal (Meeks et al., 2007). For example, if a student believes they will be able to easily remember to attend a meeting on time (i.e., PM goal), they may not use a reminder. If this student has inaccurate metacognitive judgement, they may not remember to attend their meeting, compromising their academic or professional achievement. Ultimately, metamemory beliefs can support or inhibit goal-directed behaviors. Previous literature has demonstrated that people generally tend to underestimate their behavioral PM abilities, and these memory predictions positively relate to their PM performance (Meeks et al., 2007; Schnitzspahn et al., 2011). This relationship, and metacognition more generally, may differ for various psychological disorders and conditions, including traumatic brain injury (Knight et al., 2005), obsessive compulsive symptoms (Irak et al., 2023), Parkinson’s disease (Smith et al., 2011), alcohol abuse (Le Berre et al., 2016), post-traumatic stress disorder (Sacher et al., 2018), and depression (Soderstrom et al., 2011). Depression may play a particularly interesting role in metamemory for PM, based on the potential differing frameworks for depression and metamemory (Sax et al., 2023; Soderstrom et al., 2011).

**Depression and Metamemory for Prospective Memory**

Overall, the field currently lacks thorough research assessing the relationship between metamemory for PM and depression, although three relevant studies provide insight on the topic. While Kalska et al. (1999) and Schweizer et al. (2018) did not assess metamemory specifically related to PM, both studies indicated that participants with higher depression levels reported more negative metamemory beliefs. Only Huber et al. (2022) specifically assessed metamemory for PM, demonstrating that college students with increased depressive symptoms reported significantly more negative metamemory beliefs for their behavioral PM abilities on the Prospective and Retrospective Memory Questionnaire (PRMQ) compared to non-depressed students. Interestingly, both the depressed and non-depressed participants were comparably inaccurate in their predictions of their behavioral PM performance (Huber et al., 2022). Further, when comparing men and women, Huber et al. (2022) found that women demonstrated higher reports of depression, more negative metamemory beliefs for PM, and significantly more inaccurate predictions in comparison to men. These results indicate that metamemory for PM may be particularly sensitive to depression, although the level of increased depressive symptoms is important for determining the accuracy of metamemory for PM beliefs (Huber et al., 2022). While these studies suggest that increased depression levels may predict more negative metamemory for PM beliefs, further research is needed to better understand this relationship. By assessing the role of depression in metamemory for PM, researchers can support the personal, professional, and academic success of college students.

**Depression and the Neurocognitive Components of Prospective Memory**

Another important gap in the literature is the lack of studies separating PM into its two underlying neurocognitive components using electroencephalogram/event-related potentials (EEG/ERPs), specifically components related to cue detection and intention retrieval, when examining how depression may relate to cognitive factors that contribute to goal-directed abilities. Since PM is a broad form of cognition that captures other additional abilities, more recent research has shifted towards breaking PM into its core neurocognitive components to assess potential influences on these components (Chen et al., 2015; Ji et al., 2022). Cue detection is the moment somebody notices that they must carry out their intended future-oriented goal. The N300 is an ERP component that characterizes the cue detection response during a PM task (West & Krompinger, 2005). It is represented by a negative peak in the occipital–parietal region between 200 and 400 ms after stimulus onset (West et al., 2001). Intention retrieval is the process of recalling the intended future-oriented goal from memory. The prospective positivity is an ERP component that characterizes the intention retrieval response (West et al., 2001). It is represented by a sustained positive peak over the parietal region between 500 and 1000 ms after stimulus onset (West et al., 2001).

Unfortunately, the relationship between depression, cue detection, and intention retrieval has not been thoroughly examined, although previous work has suggested that intention retrieval may be sensitive to depressive symptoms. A review paper by McFarland & Vasterling (2018) divided PM into five phases (development, maintenance/monitoring, retrieval, inhibition, and execution); upon examining studies assessing PM and depression, the researchers stated that PM impairments in depressed individuals may be driven by the maintenance/monitoring and retrieval phases of PM (McFarland & Vasterling, 2018). During the maintenance/monitoring phase, individuals actively sustain focus on the intended task while scanning the environment for the relevant cue (McFarland & Vasterling, 2018). In the retrieval phase, individuals recall the intended goal from memory to execute the task upon receiving the cue. Based on the cognitive demands of the two neurocognitive components of PM, the maintenance/monitoring and retrieval phases most align with intention retrieval, although cue detection may still be implicated. Overall, the precise relationship between the neurocognitive components of PM and depression remains unclear.

**Metamemory, Depression and the Neurocognitive Components of Prospective Memory**

The current study will expand on previous work assessing how metamemory beliefs may predict the neurocognitive components of PM by further examining if metamemory moderates the relationship between depression levels and the neurocognitive components of PM. While previous research has examined ERPs generally related to metacognitive abilities, no studies have assessed ERPs for metacognition in any clinical populations, including depression. Examining various influences and psychological states that could be related to changes in cue detection and intention retrieval is extremely important, as these two neurocognitive components work together for the accomplishment of goal-directed behaviors, yet they are comprised of distinct neural and cognitive factors. By specifically investigating how cue detection and intention retrieval vary in different populations, researchers can have a better understanding of how psychological states interact with the distinct neurocognitive capacities that drive goal-directed behaviors.

While the combined role of metamemory and depression on the neurocognitive components of PM has not previously been investigated, Da Silva Coelho et al. (2023) suggested that metamemory may play a general buffering role for age, PM abilities, and depression. Da Silva Coelho et al. (2023) investigated how depressive systems, metamemory, and age interact on behavioral PM abilities. The study examined differences in these relationships in participants between two groups: young-older adults (70 to 80 years old) and old-older adults (above 80 years old). In those with low depressive symptoms and negative metamemory beliefs, behavioral performance on a PM task was better in the young-older group compared to the old-older group. There was no age-related effect in those with low depressive symptoms and positive metamemory beliefs such that behavioral PM performance was equal between both age groups. A different pattern emerged for high depressive symptoms: in those with high depression symptoms and positive metamemory beliefs, behavioral performance on a PM was better in the young-older group compared to the old-older group.

Altogether, this study suggests that positive metamemory beliefs may be a protective factor to mitigate behavioral PM impairments in older adults, and that there could be an interaction between metamemory and depression (Da Silva Coelho et al., 2023). Importantly, however, this study did not examine the neurocognitive components of PM, or young adults, as is the aim of the current study.

To summarize previous research, it is possible that individuals with increased depression levels report more negative PM metamemory beliefs, and demonstrate a reduced prospective positivity amplitude (i.e., intention retrieval). One conceptual framework suggests that metacognitive beliefs may be somewhat accurate in depressed individuals (Soderstrom et al., 2011), while another framework suggests that metacognitive beliefs may be more negative in depressed individuals (Sax et al., 2023). Further, metamemory beliefs and depression levels may interact with age (Da Silva Coelho et al., 2023). Based on these combined findings, it follows that depression and metamemory may interact with each other when predicting the neurocognitive components of PM in younger adults. These results could provide information as to how depression levels and beliefs of one's own memory abilities relate to cue detection and intention retrieval, which could contribute to how depressed individuals allocate their cognitive resources and support their goal-directed abilities.

**Statement of Purpose**

The present study expands the field by investigating how depression levels predict metamemory for PM and the neurocognitive components of PM, measured via the N300 and the prospective positivity ERPs. Further, the study assesses if varying levels of depression and metamemory interact to predict the neurocognitive components of PM. The use of EEG/ERPs allows for the examination of the relationship between depression levels with either neural component of PM, and to determine if metamemory moderates the relationship between depression and the neural correlates of PM. With this data, researchers can offer guidance to college students experiencing depressive symptoms on how to approach their memory abilities, apply memory strategies, and accomplish their intended goals. To the author's knowledge, this is the first study that utilizes EEG/ERPs when investigating depression and metamemory for PM in college students.

**Hypothesis 1**

Based on previous work suggesting that beliefs and predictions of memory performance are more negative in individuals with depressive symptoms (Kalska et al., 1999, Schweizer et al., 2018; Huber et al., 2022), I hypothesize that increased depression levels, measured by Patient Health Questionnaire-9 (PHQ-9) and the Center for Epidemiological Studies Depression Scale (CES-D), will predict more negative subjective metamemory ratings, memory confidence, and memory predictions, assessed using the PM subscale of the PRMQ, the Cognitive Confidence subscale of the MCQ-30, and predictions for task performance, respectively.

**Hypothesis 2**

While the relationship between depression and the neurocognitive components of PM has been largely unexplored, McFarland and Vasterling's (2018) review suggests that intention retreival may be more susceptible to depression-related impairments. Based on this work, I hypothesize that increased depression will predict decreased prospective positivity amplitudes.

**Hypothesis 3**

Previous research has suggested that some level of depression may not significantly impair metamemory beliefs, while severe levels of depression may be related to more negative metamemory beliefs (Soderstrom et al., 2011). Also, metamemory may play a buffering role in behavioral PM abilities for older adults experiencing depression (Da Silva Coelho et al., 2023). The potential variability in the relationship between metamemory beliefs and depression could result in an interaction effect on the neurocognitive components of PM (i.e., cue detection and intention retrieval). Since intention retrieval may be more vulnerable to depression levels

(McFarland & Vasterling, 2018), this component of PM could be particularly sensitive to an interaction between metamemory beliefs and depression. Based on this framework, I hypothesize that the relationship between depression levels and the prospective positivity will vary based on metamemory beliefs. If the interaction is significant, interpretation of the interaction will take precedence over the previously stated main effects in hypotheses 1 and 2.

See Figure 1 for a conceptual model of the proposed hypotheses. Overall, examining these behavioral and neural will indicate the degree to which depression is related to metamemory beliefs, the relationship between depression and the neural components of PM, and if depression levels interact with metamemory beliefs when predicting the neural components of PM. With this data, the present study will be able to determine the potential role of both depression and metamemory beliefs in understanding the neurocognitive components of PM.

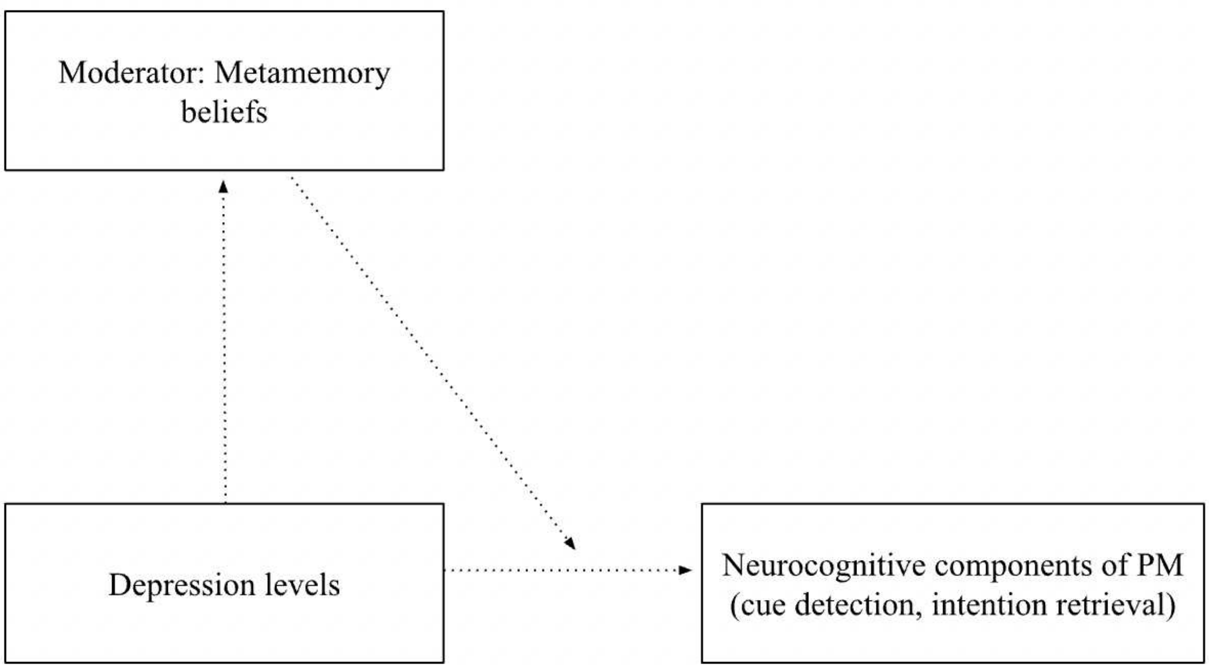



*Figure 1*. Model Relating Depression to the Components of PM with Metamemory Beliefs as the Moderator. The relationship between depression levels and the components of PM, and depression levels and metamemory beliefs will be assessed in this study. Further, the interaction between depression levels and metamemory beliefs on the components of PM will be examined.

## 3.3. METHODS

### Participants

Methods for this study were almost identical to the methods from Study 1. I used data from the same 80 participants recruited for Study 1. A power analysis was conducted using G*Power to determine the sample size required to detect small effect sizes in a fixed model regression analysis with a total of five predictors (including main effects, the interaction term, and covariates; Faul et al., 2007). With a desired power level of .80 and an alpha level of .05, the analysis indicated that a sample size of 70 participants would be appropriate to adequately detect small effect sizes. Prior to coming to the lab, potential participants completed a demographics survey assessing biological sex, gender, age, race, ethnicity, socioeconomic status, handedness, and history of epilepsy. Exclusion criteria included being below the age 18, not having normal or corrected hearing and vision, and a history of seizures. Corrected hearing and vision were necessary for participants to receive the instructions and carry out the task. Individuals with a history of epilepsy were excluded due to the irregularity in neural electrical activity associated with seizures, which could lead to irregular EEG readings. The other measures in the survey were not used to exclude participants, instead reported to fully convey the demographic characteristics of the sample.

To ensure variability in depression levels, potential participants also completed the Patient Health Questionnaire-9 (PHQ-9; Kroenke et al., 2001) during the screening process. Students scoring in the upper and lower quartiles of the PHQ-9 scores were invited to participate in the lab portion of the study (Xia et al., 2020). The PHQ-9 was used to screen participants into the study since it is comparable to semi-structured diagnostic interviews in sensitivity and specificity for detecting major depressive disorder (Levis et al., 2019).

Ninety-two participants completed the study. Twelve participants were excluded due to not understanding the task, with an accuracy lower than 10% on the PM trials. With these exclusions, there was final *n* of eighty ($M_{age}$=19.45, $SD_{age}$=2.75, 3 left-handed, gender identity: 56 women, 4 gender fluid individuals, 1 transgender woman, 3 transgender men). See Table 1 for the full demographics of the sample.

**General Procedure**

Participants were consented and then completed the following surveys: the Prospective and Retrospective Memory Questionnaire (PRMQ; Smith et al., 2000), the Cognitive Confidence Subscale of the Metacognition Questionnaire (MCQ-30; Cartwright-Hatton & Wells, 1997), and the Center for Epidemiological Studies Depression Scale (CES-D; Radloff, 1977). The primary psychological measures of the study were the PRMQ, Cognitive Confidence subscale of the MCQ-30, PM task performance predictions, CES-D, and PHQ-9. The PRMQ was utilized due to previous studies successfully using the survey to assess metamemory for PM (Kliegel & Jager, 2006; Smith, 2016; Smith et al., 2011). The MCQ-30 Cognitive Confidence subscale was used based on previous research implementing this survey to measure more general metamemory beliefs with a PM task (Swain et al., 2023). The CES-D was used to ensure the study was capturing the key symptoms of depression that may pertain to PM based on previous research utilizing this survey to assess metacognition and depression in college students (Soderstrom et al., 2011). Both the PHQ-9 and CES-D were used in this study to capture a more robust spectrum of depression symptomology: the PHQ-9 is useful for assessing clinical levels of major depressive disorder, while the CES-D describes a broader range and severity of depressive experiences (Amtmann et al., 2014; Levis et al., 2019; Siddaway et al., 2017).

Following completion of the surveys, the participants were fit with an EEG cap and were provided with task instructions to complete the PM task. The researcher provided participants with instructions for the task and gave them the opportunity to ask questions. Next, the participants provided the researcher with a performance prediction for the PM task, on a scale from 0% - 100%. This performance prediction was used based on a previous study examining metacognitive abilities and PM performance (Meeks et al., 2007). Upon completion of the task, participants were debriefed and participation in the experiment was documented for course credit/extra credit.

***Measures***

Prospective and Retrospective Memory Questionnaire (PRMQ; Smith et al., 2000): Metamemory of PM performance was quantified as a single continuous variable from adding the item responses of the PM subscale of the PRMQ. A higher score indicated increased reports of perceived memory problems. See Appendix A for a reproduction of the measure, and Study 1 for a more extensive description of the measure.

Cognitive Confidence Subscale of the Metacognitions Questionnaire (MCQ-30; Cartwright-Hatton & Wells, 1997): Cognitive confidence was quantified as a single continuous variable from adding the item responses. Higher scores indicated lower cognitive confidence. See Appendix A for a reproduction of the measure, and Study 1 for a more extensive description of the measure.

Performance prediction for PM task (Meeks et al., 2007): Performance prediction for the PM task was quantified as a single continuous variable. A higher score indicated more confidence in one's memory abilities. See Appendix A for a reproduction of the measure, and Study 1 for a more extensive description of the measure.

Patient Health Questionnaire-9 (PHQ-9; Kroenke et al., 2001): Participants reported their depression levels by indicating "Not at all", "Several days", "More than half the days", "Nearly every day" to a series of nine statements (e.g., "Little interest or pleasure in doing things," "Feeling down, depressed, or hopeless," "Trouble falling or staying asleep, or sleeping too much"). The PHQ-9 has high internal reliability ($\alpha = .89$) and high validity (Kroenke et al., 2001). Depression from the PHQ-9 was quantified as a single continuous variable from summing the item responses. A higher score indicated more severe levels of depression. See Appendix A for a reproduction of the measure.

Center for Epidemiological Studies Depression Scale (CES-D; Radloff, 1977): Participants reported their depression levels by indicating "Rarely or none of the time (less than 1 day)", "Some or a little of the time (1-2 days)", "Occasionally or a moderate amount of time (3-4 days)", "Most or all of the time (5-7 days)" to a series of twenty statements (e.g., "I was bothered by things that usually don't bother me", "I did not feel like eating; my appetite was poor", "I felt that I could not shake off the blues even with help from my family or friends"). The CES-D has high reliability ($\alpha = .85$) and validity (Radloff, 1977). Items 4, 8, 12, and 16 on the CES-D were reverse scored. Depression from the CES-D was quantified as a single continuous variable from summing the item responses. A higher score indicated more severe levels of depression. See Appendix A for a reproduction of the measure.

Visual Search PM Task: This task was used to elicit and assess the ERP components of PM (i.e., the N300 for cue detection and the prospective positivity for intention retrieval). The task was created using PsychoPy3 Experiment Builder (v2021.2.3; Peirce et al., 2019) and was adapted from West and Wymbs (2004). It had three essential components: an ongoing visual search task, a cue detection component, and an intention retrieval component. During the ongoing visual search task, participants were shown a target letter in the center of the computer screen, followed by two test letters on the left and right sides of the display. If the target letter was present in the test letters, the participant pressed V with their left index finger. If the target letter was not present in the test letter, the participants pressed B with their right index finger.

The PM components were introduced to the visual search task after the participants completed a block of the isolated visual search task. The letters D and M served as the cue detection components of PM task. If the letters D or M were present in the test letters, the participants needed to remember to select N with their right middle finger. Remembering to select N when prompted with D or M was the intention retrieval component of the PM task. This PM paradigm has been validated in previous research to elicit the desired ERP components (West & Wymbs, 2004). See Study 1 for a more detailed description of the task. See Appendix B for a reproduction of the task stimulus and instructions.

**EEG Procedure**

Electroencephalography (EEG) was recorded at a rate of 1000 Hz using SynAmps2/RT 64 Channel system (Curry7, Compumedics NeuroScan, USA) (acquisition bandwidth = 1000 Hz, sampling rate = 1000 Hz) and a 64 electrode Quik-cap Neo Net with sewn-in or affixed to skin via an adhesive patch silver-chloride sintered electrodes (Diameter = 1.5 cm; Compudics USA, Inc. Model: C190). The electrodes are placed in the cap based on the 10-20 electrode placement standard. A .01 Hz high-pass filter and a 100 Hz low-pass filter was used during recordings. Electrode placements followed the Quik-cap 64 system and included all electrodes (Fpz, Fz, Pz, Poz, Oz, Fp1, Fp2, Af3, Af4, F1, F2 F3, F4, F5, F6 F7, F8, F11, F12, Fc1, Fcz, Fc2, Fc3, Fc4 Fc5, Fc6, Ft11, Fc12, C1, Cz, C2, C3, C4, C5, C6, T7, T8, Tp7, Tp8, Cp1, CPz, Cp2, Cp3, Cp4, Cp5, Cp6, P1, P2, P3, P4, P5, P7, P6, P8, Po3, Po4, O1, O2, Po7, Po8, Cb1, Cb2, left mastoid M1, right mastoid M2, VEOU, VEOL, HEOL, HEOR). Eye movements were monitored with electrode placement on positions lateral and superior of the left eye for Vertical Electrooculogram (EOG), and the outer corner of each eye for Horizontal EOG. The reference electrode was placed between Cz and CPz. The ground electrode was AFz. During recording, all electrodes were referenced to electrode Cz (Rice et al., 2024).

**EEG/ERP Analyses**

N300: Cue detection was calculated as a single continuous variable measured from the average amplitude (μV) of the neural responses for correct prospective-cue trials between 200 and 400 ms, from electrodes O1, Oz and O2. A stronger negative amplitude indicated an accentuated N300, suggesting a larger cue detection response (Chen et al., 2015; Rice et al., 2024; West & Wymbs, 2004).

Prospective positivity: Intention retrieval was calculated as a single continuous variable measured from the average amplitude (μV) of the neural responses for correct prospective-cue trials between 500 and 1000 ms, from electrodes P3, Pz and P4. A stronger positive amplitude indicated an enhanced prospective positivity, suggesting a larger intention retrieval response (Chen et al., 2015; Rice et al., 2024; West & Wymbs, 2004).

EEG data were processed in MATLAB (version R2022b) using EEGLAB (version 2024.0) with the ERPLAB plug-in (version 10.04; Lopez-Calderon & Luck, 2014). A 0.1–30 Hz zero-phase-shift bandpass filter was applied. Ocular artifacts were corrected using the Independent Component Analysis feature in EEGLAB. The EEG data were re-referenced to an average reference and trials exceeding a voltage of +/- 100 μV were removed from trials. The

ERP epoch included -200 to 1200 ms of activity around stimulus onset (Rice et al., 2024). To analyze the electrode clusters, mean voltages of electrodes O1, Oz, and O2 were averaged to measure the N300. Mean voltages of electrodes P3, Pz, and P4 were averaged to measure the prospective positivity, as has been performed in previous literature (Chen et al., 2015; Groot & Strien, 2019; Zhang et al., 2019).

**Statistical Methods**

Multiple linear regression analyses were conducted in R (version 4.3.1; R Core Team, 2021) to examine associations among metamemory beliefs reported from the PRMQ, Cognitive Confidence scale, performance predictions, depression levels measured from the CES-D and PHQ-9, and the neurocognitive components (i.e., N300 and the prospective positivity), with participant age and gender as control variables in the models.

Interaction analyses were conducted using the “interactions” package in R (Long, 2024) to examine whether the relationship between depression (i.e., the independent variable) and neurocognitive components (i.e., dependent variable) was moderated by metamemory. Interaction terms were created by multiplying standardized scores for metamemory measures (i.e., PRMQ, Cognitive Confidence scale, performance predictions) with standardized depression scores (i.e., CES-D, PHQ-9). The interaction terms were included in the regression models as the independent variables, with the N300 and prospective positivity as the dependent variables. The covariates, age and gender, were also included in the interaction models. For significant or marginally significant interaction models, simple slopes analyses were conducted to further explore the nature of the interaction. Specifically, the slopes of depression on the ERPs would be examined at high (+1 standard deviation), average, and low (−1 standard deviation) levels of metamemory.

Gender and age were included as covariates to control for their varying effects on metamemory, depression, and ERPs varying with age and gender (Bowman et al., 2015; Collier Villaume et al., 2023; Hertzog et al., 2019; Salk et al., 2017; West et al., 2003). Controlling for these variables isolated the role of metamemory and depression on the relevant ERPs, without confounding effects of age and gender. Gender was dummy coded in three groups for the analyses to account for individuals outside the gender binary (e.g., man, women, and transgender + nonbinary) (DuBois & Shattuck-Heidorn, 2021).

Effect sizes were measured using partial R-squared, calculated from the linear regressions. To obtain effect sizes, R-squared values were calculated for both the full models (including main effects, interaction terms, and covariates) and reduced models (excluding the independent variable or interaction term of interest). Then, the partial R-squared was calculated as the difference between the R-squared values for the full and reduced models, capturing the unique effect size of the independent variables while controlling for of age and gender. All tests were two tailed ($\alpha = .05$).

***Missing Data***

There were no instances of missing data in the sample.

***Interpretation of Analyses***

The interpretations for this study were similar to those of Study 1. In all analyses, standardized betas and effect sizes were used to convey the strength and scope of the relationships. Although *p*-values were reported and used to assess statistical significance, the emphasis was placed on effect sizes and standardized betas. While *p*-values help determine the likelihood that findings are due to chance, they do not capture the magnitude of effects and are influenced by sample size (Sullivan & Feinn, 2012). In contrast, standardized betas and effect sizes provide important insights beyond what *p*-values alone can offer. For the regression models, standardized betas ($\beta$) represent the strength and direction of the relationships (van Ginkel, 2020). Partial R-squared ($\eta^2$) was used as the measure of effect size, indicating the proportion of variance in the dependent variables explained by the independent variables after controlling for covariates (Levine & Hullett, 2002; Stoffel et al., 2021). For the simple slopes analyses, unstandardized betas (*b*) were reported, indicating the unit change in the dependent variable for every one unit change in the independent variable (Nieminen, 2022).

According to Cohen (1988), partial R-squared and standardized beta values below .1 represent very small effect sizes, values between .1 and .3 represent small effects, .3 to .5 indicate medium effects, and values above .5 suggest large effects. Unstandardized betas do not have a normalized strength, but they can be assessed based on the magnitude of the scales. Given the importance of betas and effect sizes, the interpretation of results will prioritize these measures over *p*-values. However, *p*-values will still be reported, with $\alpha = .05$ indicating statistical significance and $\alpha = .10$ denoting marginal significance.

# 3.4. RESULTS

## Descriptive Statistics

Descriptive statistics for depression levels, metamemory measures, the N300, the prospective positivity, gender, and age, and zero-order correlations between these variables are provided in Table 2. The depression measures were highly correlated with each other ($p < .01$). Gender was correlated with metamemory assessed by the PRMQ ($p < .05$), as well as depression ($p < .05$). Age was not correlated with any of the variables of interest. The main effects and interaction effects were run without gender or age as covariates, and the results did not meaningfully change.

High scores on the CES-D and PHQ-9 indicate high levels of depression. More specifically for the PHQ-9, a score of 0 – 4 indicated minimal to no depression, 5 – 9 indicated mild depression, 10 – 14 indicated moderate depression, 15 – 19 indicated moderately severe depression, and 20-27 indicated severe depression. Based on PHQ-9 scores, 51% of participants indicated low to no depressive symptoms, 24% of participants reported moderate depression, 21% of participants reported moderately severe depression, and 4% of participants indicated severe depression. The mean score of the PHQ-9 was 8.14, suggesting a slight skew towards lower depression levels, although high levels of depression are represented in the sample (See Table 1).

For the CES-D, a score of 21 or above indicates high risk of severe depression. The lowest possible score is 0, and the highest possible score is 60. Based on CES-D scores, 39% of participants reported low risk of depression, and 61% participants reported high risk of severe depression symptoms. The mean score of the CES-D was 26.40, suggesting the sample reported higher experiences of depression symptomology on the CES-D (See the Table 1).

The range for the PRMQ is 8 to 40, with lower scores indicating more positive beliefs about PM abilities and higher scores reflecting more negative beliefs. In this sample, the average PRMQ score was 24, ranging from 9 to 39 (see Table 1). This distribution showed variability in PRMQ scores without a notable skew towards either positive or negative PM beliefs.

The range for the Cognitive Confidence scale is 6 to 24. Lower scores reflect more positive beliefs about cognitive abilities, while higher scores indicate more negative beliefs. In this sample, the average Cognitive Confidence score was 12, with a range of 6 to 22 (see Table 1). This distribution suggested some variation in Cognitive Confidence scores, with a slight skew toward more negative cognitive beliefs.

The range for the PM task performance prediction scale is 0% to 100%. Lower scores indicate less confidence in task performance, while higher scores suggest greater confidence. In this sample, the average performance prediction score was 71%, ranging from 15% to 100% (see Table 1). This distribution revealed some variation in task performance predictions, though there was a stronger skew toward higher predictions, indicating that the sample generally had greater confidence in their task-specific performance.

**Main effects of Metamemory and Depression**

The results revealed a significant positive association between PHQ-9 scores and PRMQ scores, and Cognitive Confidence scores ($\beta$ =.62, $p$ < .01, $\eta^2$ = .366; $\beta$ =.46, $p$ < .01, $\eta^2$ = .203). See Figure 2. PHQ-9 scores were not significantly related to performance predictions ($\beta$ = .02, $p$ = .884, $\eta^2$ = .000). There was a positive association between CES-D scores, PRMQ scores, and Cognitive Confidence scores ($\beta$ = .65, $p$ <.01, $\eta^2$ = .395; $\beta$ = .55, $p$ < .01, $\eta^2$ = .280). See Figure

3. CES-D scores were not significantly related to performance predictions ($\beta$ = -.08, $p$ = .478, $\eta^2$ = .006). All analyses controlled for age and gender.

**Main effects of Depression and ERPs**

PHQ-9 scores and CES-D scores were not related to prospective positivity amplitude ($\beta$ = -.09, $p$ = .416, $\eta^2$ = .008; $\beta$ = -.09, $p$ = .461, $\eta^2$ = .007). PHQ-9 scores and CES-D scores were also not related to N300 amplitude ($\beta$ = -.12, $p$ = .328, $\eta^2$ = .013; $\beta$ = -.08, $p$ = .508, $\eta^2$ = .006). All analyses controlled for age and gender.

**Interaction Effects of Metamemory on Depression and ERPs**

***The Prospective Positivity***

In the model predicting the prospective positivity amplitude, the relationship between PHQ-9 and the prospective positivity was not moderated by the PRMQ, Cognitive Confidence, or performance predictions ($\beta$ = -.005, $p$ = .251, $\eta^2$ = .012; $\beta$ = -.004, $p$ = .663, $\eta^2$ = .002; $\beta$ = .000, $p$ = .996, $\eta^2$ = .000). The role of CES-D scores on the prospective positivity amplitude was not moderated by the PRMQ, Cognitive Confidence, or performance predictions ($\beta$ = -.003, $p$ = .331, $\eta^2$ = .011; $\beta$ = -.004, $p$ = .542, $\eta^2$ = .005; $\beta$ = .000, $p$ = .915, $\eta^2$ = .000). All analyses controlled for age and gender. There was no moderating effect of metamemory on the relationship between depression and the prospective positivity.

***The N300***

In the model predicting the N300 amplitude, the interaction between the PHQ-9 and the PMRQ was marginally significant ($\beta$ = -.02, $p$ = .061, $\eta^2$ = .046), suggesting that the relationship between the PHQ-9 and N300 may vary as a function of PRMQ scores. Simple slopes analyses revealed a potential pattern: for participants with higher PRMQ scores (+1 standard deviation), higher PHQ-9 scores may predict a stronger N300 response, although this relationship was not significant ($b$ = -.14, $p$ = .15). Participants with average PRMQ scores did not have a significant association between PHQ-9 scores and the N300 ($b$ = -.02, $p$ = .80). Participants with lower PRMQ scores (-1 standard deviation) also did not have a significant association between PHQ-9 scores and the N300 ($b$ = -.14, $p$ = .39). These results suggest that higher depression levels from the PHQ-9 may be associated with a larger N300 response in individuals with worse PRMQ scores. See Figure 4.

The interaction between the PHQ-9 and performance predictions was significant at a trend level when predicting the N300 ($\beta$ = .01, $p$ = .050, $\eta^2$ = .049), indicating that the relationship between the PHQ-9 and N300 varied as a function of performance predictions. Simple slopes analyses suggested that for participants with lower performance predictions (-1 standard deviation), higher PHQ-9 scores were a marginally significant predictor of an enhanced N300 response ($b$ = -.16, $p$ = .05). Participants with average performance predictions did not have a significant association between PHQ-9 scores and the N300 ($b$ = -.04, $p$ = .48). For participants with higher performance predictions (+1 standard deviation), higher PHQ-9 scores were not significantly related to the N300 amplitude ($b$ = .07, $p$ = .44). These findings suggest that higher depression levels from the PHQ-9 may be associated with a stronger N300 response in individuals with lower performance predictions. See Figure 5. See Figures 6 and 7 for further visualization.

The role of the PHQ-9 scores on the N300 amplitude was not moderated by Cognitive Confidence scores ($\beta$ = -.02, $p$ = .184, $\eta^2$ = .023). The relationship between the CES-D and the N300 amplitude was not moderated by the PRMQ, cognitive confidence, or performance predictions ($\beta$ = -.01, $p$ = .135, $\eta^2$ = .029; $\beta$ = -.008, $p$ = .565, $\eta^2$ = .004; $\beta$ = .003, $p$ = .192, $\eta^2$ = .022). All analyses controlled for age and gender.

# 3.5. DISCUSSION

The findings of the current study suggest that high depression levels predict worse metamemory beliefs, with a potential interaction of metamemory beliefs on the relationship between depression and cue detection. See Figure 8 for a visual representation of this model. While there were no significant main effects for depression and the neurocognitive components of PM, the PRMQ and performance predictions moderated the role of depression levels, assessed via the PHQ-9, on the N300 response at trend level. For college students with more negative metamemory beliefs, heightened depression levels predicted a larger N300 response, indicating more cognitive resources placed towards cue detection. The moderation effect of metamemory on depression and cue detection was only seen for the PHQ-9, PRMQ, and performance predictions. Since the PHQ-9 is comparable to semi-structured diagnostic for detecting major depressive disorder, these results suggest that clinical levels of depression have a unique relationship with PM-related metamemory perceptions in predicting cue detection (Levis et al., 2019). As expected, there were slight gender differences, but the results were consistent across the sample regardless of whether gender was included in the models. This is the first study that employed EEG/ERPs to examine the relationship between depression, cue detection, intention retrieval, and metamemory. The results from this study could further inform college students on how their beliefs in their cognitive abilities may have important implications for their cognitive responses and allocating resources, especially students experiencing depression.

**The Role of Metamemory on Depression and Cue Detection**

While not the primary focus of the findings, the main effects of depression on metamemory were consistent with previous findings indicating that greater reports of depression predict more negative metamemory beliefs for PM (Huber et al., 2022). Low self-worth and diminished confidence are key symptoms of depression, which aligns with the low metamemory self-appraisals seen in college students with depression found in the current study (Huber et al., 2022). Neither of the neurocognitive components were predicted by depression levels alone, suggesting that depression is not the sole psychological factor involved in different neurocognitive responses for PM. While previous literature has implicated depression in changing cue detection and intention retrieval responses, this line of research has not been thoroughly explored (Chen et al., 2013; McFarland & Vasterling, 2018). Additionally, Da Silva Coelho et al. (2023) suggested that depression levels may impair PM abilities, and metamemory beliefs could moderate how intensely depression impairs PM in older adults, but no research has applied these concepts to college students using EEG/ERPs. This study provides further evidence that depression alters a neurocognitive component of PM, cue detection, but only when individuals have low metamemory representations of their PM ability.

Importantly, McFarland & Vasterling's (2018) review of the PM and depression literature suggested that depression may impair the maintenance/monitoring and retrieval phased of PM. This framework does not explicitly differentiate cue detection from intention retrieval, although it seems to imply both may be related to depression levels. Chen et al. (2013) used eye-tracking to suggest that cue detection abilities were altered in depression-related PM impairments, as participants with higher depression levels performed worse on a PM task and spent more time attending to targets in the PM cue trials. While the researchers did not include intention retrieval in their study, their results suggest that depression may be related to changes in top-down processes of attentional control (Chen et al., 2013). The results of the current study support and expand on Chen et al.'s (2013) and McFarland and Vasterling's's (2018) work by disentangling both cue detection and intention retrieval using neurophysiology, and by demonstrating a different attention-based neural response for college students with increased depression levels and worse metamemory beliefs. These findings suggest that cue detection undergoes depression and metamemory-related changes, while intention retrieval is stable in individuals with depression, regardless of their metamemory beliefs.

Specifically, the findings align with Chen et al.'s (2013) results that adults with increased depression levels may be allocating more cognitive resources towards the attention-related aspect of the goal-directed task, cue detection, but only when the highly depressed college students have more negative self-appraisals of their PM abilities. The role of metamemory in the relationship between depression and PM-related abilities expands on Da Silva Coelho et al.'s (2023) study, which demonstrated that more positive metamemory beliefs may be a buffer for age-related PM impairments when depression levels are low. In contrast, at higher depression levels, more positive metamemory representations do not seem to play that same role. Instead, older adults with higher depression levels and more positive metamemory representations demonstrated worse PM skills (Da Silva Coelho et al., 2023). Da Silva Coelho et al.'s (2023) study did not examine how cue detection and intention retrieval were implicated, but it did suggest that varying metamemory beliefs may play a differential role in how depression alters the cognitive resources related to PM abilities. The current study elaborates on this idea by demonstrating that in participants with more negative appraisals of their PM abilities, increased depression levels predicted more cognitive resources allocated specifically towards cue detection. Additionally, no significant associations were found for more positive metamemory beliefs changing the relationship between depression and the neurocognitive components of PM. These findings suggest that more negative metamemory beliefs may be particularly informative when focusing cognitive abilities on how to perform future-oriented goals for college students experiencing depression.

While this interaction has not been thoroughly examined in past studies, previous research does provide a conceptual background to understand these findings. Depression and metamemory may interact to alter cue detection responses as opposed to intention retrieval due to the attentional biases involved in both depression and metamemory evaluations. Researchers have described depression symptoms as being highly heterogenous, with some groups of depressed individuals demonstrating impaired attention abilities, others having enhanced attentional skills, and some showing no attention changes (Keller et al., 2019). Past EEG/ERP studies have revealed increased attention responses towards negative stimuli measured from the P2 component (Fuseda et al., 2022). Regarding the metamemory literature, metamemory beliefs help individuals decide what is needed to accomplish a goal and what they should be attending to by guiding the allocation of cognitive resources based on perceived importance (Murphy & Castel, 2021). Metacognitive perceptions of how difficult a task is can alter attention specifically for a PM task, as participants who perceived a task to be more difficult placed more attention towards the PM cues than the ongoing task cues (Rummel & Meiser, 2013). Ultimately, previous work suggests that individuals with increased depression levels focus their attention on negatively salient information, and evaluations of task difficulty may guide how a person focuses their cognitive effort to complete the task (Keller et al., 2019; Rummel & Meiser, 2013).

Taken together, it is possible that reduced metamemory beliefs contribute to how difficult depressed individuals perceive a task to be, which may lead them to allocate more cognitive effort towards monitoring the environment for the cue, as reflected in the results. Participants with increased depression and more negative metamemory beliefs may view the PM task as more challenging, or they may experience a negative affective response to the PM goal due to their low confidence in their cognitive abilities, biasing their attentional response towards the PM cue. These psychological responses could explain why these highly depressed college students with low metamemory beliefs demonstrate a heightened cue detection response.

**Limitations**

It is important to note the limitations in interpreting the findings of the current study. First, the interaction effects described here are only significant at a trend level, and the effect sizes are small. While the patterns provide associations that are conceptually consistent with previous literature, the strength of these relationships should be interpreted cautiously. Based on the marginal significance and small effect sizes, there are likely other psychological and cognitive factors that contribute to cue detection responses.

Additionally, this study employed an event-based, focal, computerized PM task, which could limit the ecological validity of the results. PM performance can also require time monitoring skills, which was not reflected in this study. While both event-based and time-based PM tasks elicit the N300 and the prospective positivity components, future studies should examine if depression and metamemory have the same role on the neurocognitive components for time-based PM skills.

Another important limitation is the lack of postdictions included in the study, which is a perceived performance evaluation given by the participant after completion of the task (Meeks et al., 2007). The participants did not report how they believed they were allocating their cognitive resources, so we are unable to determine if the participants were accurate in their judgements of which neurocognitive component of PM they were prioritizing to perform the task. For example, it is possible that participants with depression believe they are focusing on remembering the goal, but that their prospective positivity response does not reflect this impression. It is also possible that participants with depression and more negative metamemory representations are aware that they are allocating more effort towards monitoring the environment for the cue. Future studies should include postdictions to ask college students how they believe they allocated their cognitive resources during the tasks, as this information can help researchers advise college students with depression on how to strengthen their PM-related skills.

Lastly, this study's sample did not reflect sufficient diversity across racial, ethnic, socioeconomic, and gender backgrounds. Race, gender, and socioeconomic status can shape individuals' distinct life experiences, including encounters with discrimination, social isolation, and limited access to resources (Roberts et al., 2020). These experiences can be associated with differences in psychological factors such as memory, executive function, neural activity, brain development, and mental health (Cavanaugh & Abu Hussein, 2020; Moriguchi & Shinohara, 2019; Navarro-Carrillo et al., 2020; Perera-W. A. et al., 2021; Roberts et al., 2020; Short et al., 2013). With these considerations, the findings of this study may not be applicable to individuals from all socioeconomic, racial, or gender groups. Future research should prioritize a more inclusive and varied representation of participants across these groups.

## Future Directions and Conclusions

Continued work should attempt to further elucidate the role of metamemory representations in moderating the relationship between depression levels and attention resources. For example, future studies should try to manipulate the difficulty of the task, or the perceived difficulty of the task, to examine if changing the objective and metacognitive demands of the task alters how depressed and non-depressed participants allocate their cognitive resources. Do individuals with depression put less cognitive effort towards cue detection when they perceive the task to be more difficult, or will they further compensate by putting more cognitive resources towards both neurocognitive components of PM? Future work could also implement a PM task that has intentionally manipulated negative or positive stimuli, as this would allow researchers to investigate if individuals with depression and more negative metamemory beliefs place more attention and cognitive effort towards emotionally valanced cues. These lines of research would determine if there are other psychological and cognitive factors that overpower the effects seen in the current study so that depressed individuals shift their cognitive resources elsewhere. This work would also support the theoretical background of the current study's findings by examining if depression levels and metamemory beliefs are related to perceived difficulty and affective components of a goal-directed task.

The findings of the current study reveal that as depression levels increase and students have more negative PM-related metamemory beliefs, they may experience an increased cue detection response. Reduced belief in one's PM abilities for highly depressed college students could lead to students spending more cognitive effort monitoring the environment for the cue. The more their depression levels increase with their negative metamemory beliefs, the greater their cue detection response is. This neurocognitive response could be a compensatory mechanism, as highly depressed participants who believe they have low memory abilities may try to compensate by allocating more attentional resources to detecting the cue for the task. The findings of the current study have important implications for how depression and metamemory beliefs interact to change the neurocognitive responses of PM, as college students experiencing depression can understand how their negative memory beliefs may result in them placing greater cognitive resources towards monitoring the environment for their goal-related cue. If students with depression wish to change how they focus their cognitive efforts when completing a future-oriented goal, they may be able to do so by addressing their negative metamemory evaluations.

**TABLE 1**
*Descriptive statistics*

| Variable Name | *n* | Percent | Mean | Standard Deviation | Standard Error | Min. | Max. | Range |
|---|---|---|---|---|---|---|---|---|
| Age | - | - | 19.45 | 2.75 | .31 | 18 | 36 | 18 |
| Gender Identity | | | - | - | - | - | - | - |
| Man | 16 | 20.00 | | | | | | |
| Woman | 56 | 70.00 | | | | | | |
| Transgender Man | 3 | 3.75 | | | | | | |
| Transgender Woman | 1 | 1.25 | | | | | | |
| Gender Fluid | 4 | 5.00 | | | | | | |
| Race | | | - | - | - | - | - | - |
| White | 71 | 88.75 | | | | | | |
| Black or African American | 1 | 1.25 | | | | | | |
| Asian | 1 | 1.25 | | | | | | |
| Native American or Alaska Native | 1 | 1.25 | | | | | | |
| Native Hawaiian or Other Pacific Islander/White | 1 | 1.25 | | | | | | |
| Native American or Alaska Native/Black or African American | 1 | 1.75 | | | | | | |
| Do not wish to respond | 3 | 3.75 | | | | | | |
| Ethnicity | | | - | - | - | - | - | - |
| Not Hispanic of Latinx | 65 | 81.25 | | | | | | |
| Hispanic or Latinx | 14 | 17.5 | | | | | | |
| Do not wish to respond | 1 | 1.25 | | | | | | |
| Average Years of Parental Education (Socioeconomic Status) | - | - | 15.49 | 3.57 | .40 | 3 | 22 | 19 |
| PRMQ Score | - | - | 24.31 | 6.94 | .78 | 9 | 39 | 30 |
| Cognitive Confidence Score | - | - | 11.54 | 4.02 | .45 | 6 | 22 | 16 |
| Prediction Performance (%) | - | - | 71.30 | 17.36 | 1.94 | 15 | 100 | 85 |
| PHQ-9 | - | - | 8.14 | 7.04 | .79 | 0 | 24 | 24 |
| CES-D | - | - | 26.40 | 9 | 1.01 | 15 | 48 | 33 |

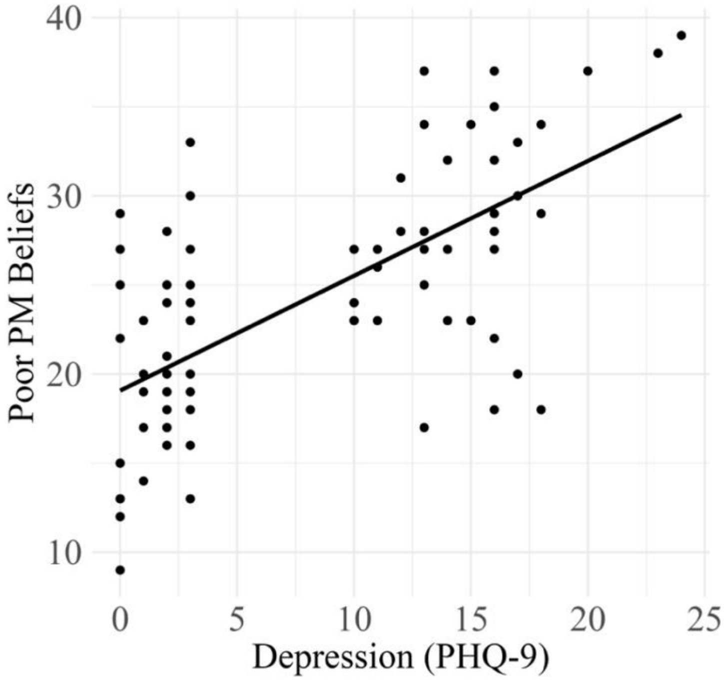
**TABLE 2**

*Means, standard deviations, and correlations with confidence intervals*

| Variable | *N* | *M* | *SD* | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1. Prospective Positivity | 80 | 1.93 | 1.93 | | | | | | | |
| 2. N300 | 80 | 0.35 | 3.90 | .39** [.19, .56] | | | | | | |
| 3. PRMQ | 80 | 24.31 | 6.94 | -.26* [-.45, -.04] | -.07 [-.28, .16] | | | | | |
| 4. Cognitive Confidence | 80 | 11.54 | 4.02 | -.17 [-.37, .05] | .03 [-.19, .25] | .65** [.50, .76] | | | | |
| 5. Performance Prediction | 80 | 71.30 | 17.36 | -.02 [-.24, .20] | -.13 [-.34, .10] | -.12 [-.33, .10] | -.10 [-.31, .12] | | | |
| 6. PHQ-9 | 80 | 8.14 | 7.04 | -.07 [-.29, .15] | -.09 [-.30, .13] | .65** [.51, .76] | .48** [.29, .63] | .01 [-.21, .23] | | |
| 7. CES-D | 80 | 26.40 | 9.00 | -.07 [-.28, .16] | -.05 [-.27, .17] | .68** [.54, .78] | .56** [.38, .69] | -.09 [-.31, .13] | .81** [.71, .87] | |
| 8. Age | 80 | 19.45 | 2.75 | -.17 [-.37, .05] | -.03 [-.25, .19] | -.07 [-.28, .15] | -.09 [-.30, .13] | -.15 [-.36, .07] | -.12 [-.33, .10] | -.10 [-.31, .12] |
| 9. Gender[1] | 72 | - | - | .11 [-.12, .33] | .06 [-.18, .29] | .17 [-.06, .39] | .20 [-.04, .41] | -.20 [-.42, .03] | .07 [-.17, .29] | .12 [-.11, .34] |
| 10. Gender[2] | 64 | - | - | -.08 [-.32, .17] | .07 [-.18, .31] | .27* [.03, .48] | .03 [-.22, .27] | .10 [-.15, .34] | .28* [.03, .49] | .24 [-.01, .45] |
| 11. Gender[3] | 24 | - | - | .00 [-.39., .41] | .16 [-.26, .53] | .47* [.09, .74] | .29 [-.13, .62] | -.12 [-.50, .30] | .45* [.06, .72] | .43* [.03, .71] |

*Note. M* and *SD* are used to represent mean and standard deviation, respectively. Point-biserial correlation coefficients were calculated to assess the relationships between the binary categorical variable (gender) and the continuous variables. Pearson's correlation coefficients were calculated to evaluate the correlations between the continuous variables. Values in square brackets indicate the 95% confidence interval for each correlation. The confidence interval is a plausible range of population correlations that could have caused the sample correlation (Cumming, 2014). * indicates $p < .05$. ** indicates $p < .01$. Gender[1]: Man = 0, Woman = 1. Gender[2]: Women = 0, Transgender + nonbinary = 1. Gender[3]: Men = 0, Transgender + nonbinary = 1.

A)




B)

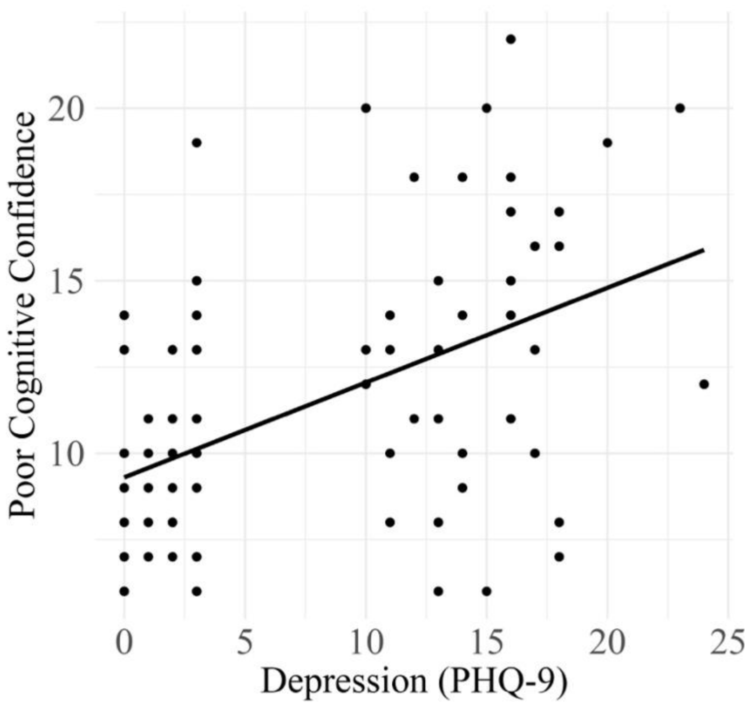
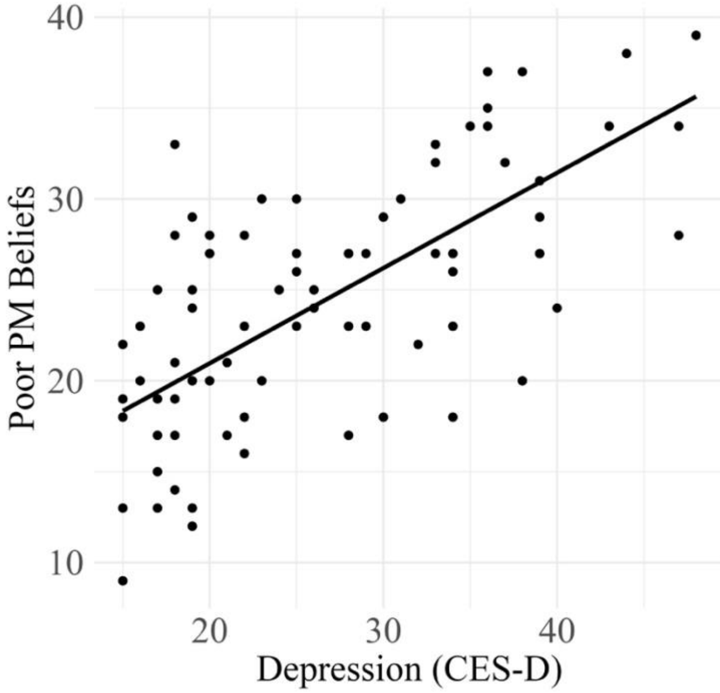



*Figure 2.* Results of Clinical Depression Related to Metamemory. A scatterplot showing an increase in clinical depression levels, measured by the PHQ-9, is associated with higher self-assessment of prospective memory failures, measured by the PRMQ (A), and a higher perception of poor cognitive confidence, measured by the Cognitive Confidence scale (B).

A)




B)

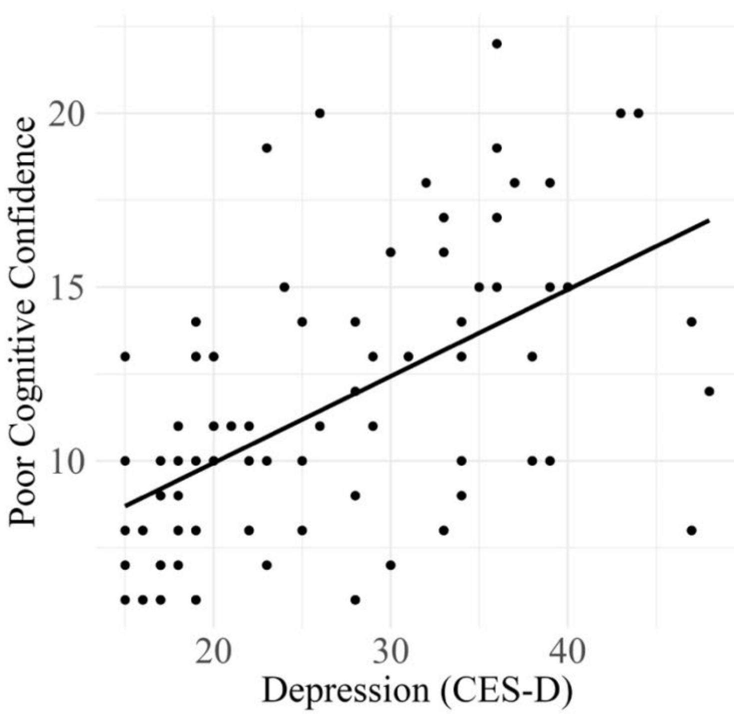



*Figure 3.* Results of Depression Levels Related to Metamemory. A scatterplot showing an increase in depression symptoms, measured by the CES-D, is associated with higher self-assessment of prospective memory failures, measured by the PRMQ (A), and a higher perception of poor cognitive confidence, measured by the Cognitive Confidence scale (B).

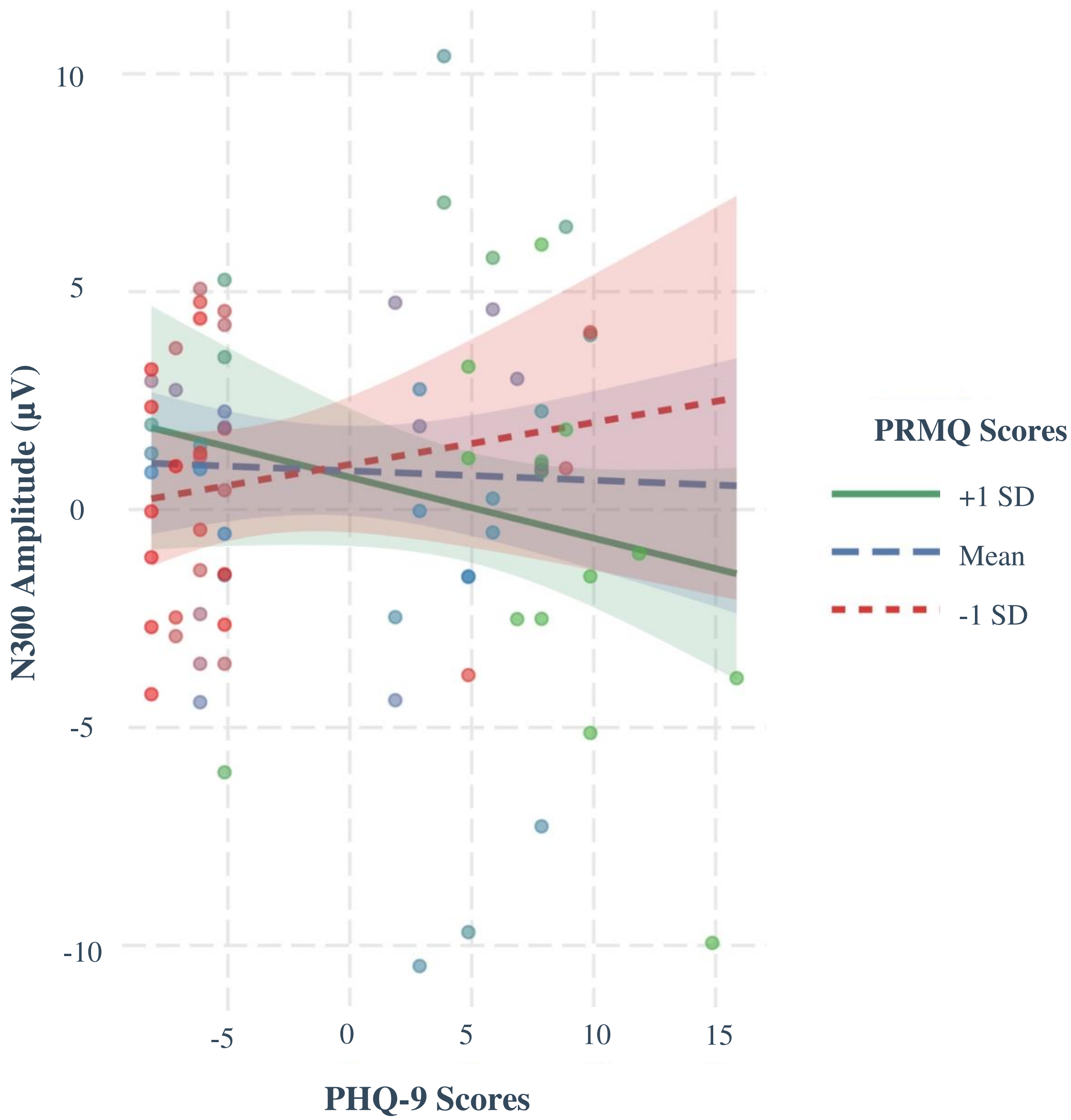



*Figure 4.* Results of Depression Levels Related to the N300 Amplitude Moderated by Metamemory. A scatterplot showing that in participants with higher judgements of PM failures, increased depression levels, measured by upper and lower quartile scores from the PHQ-9, predict a larger N300 response. The shaded areas represent 95% confidence intervals.

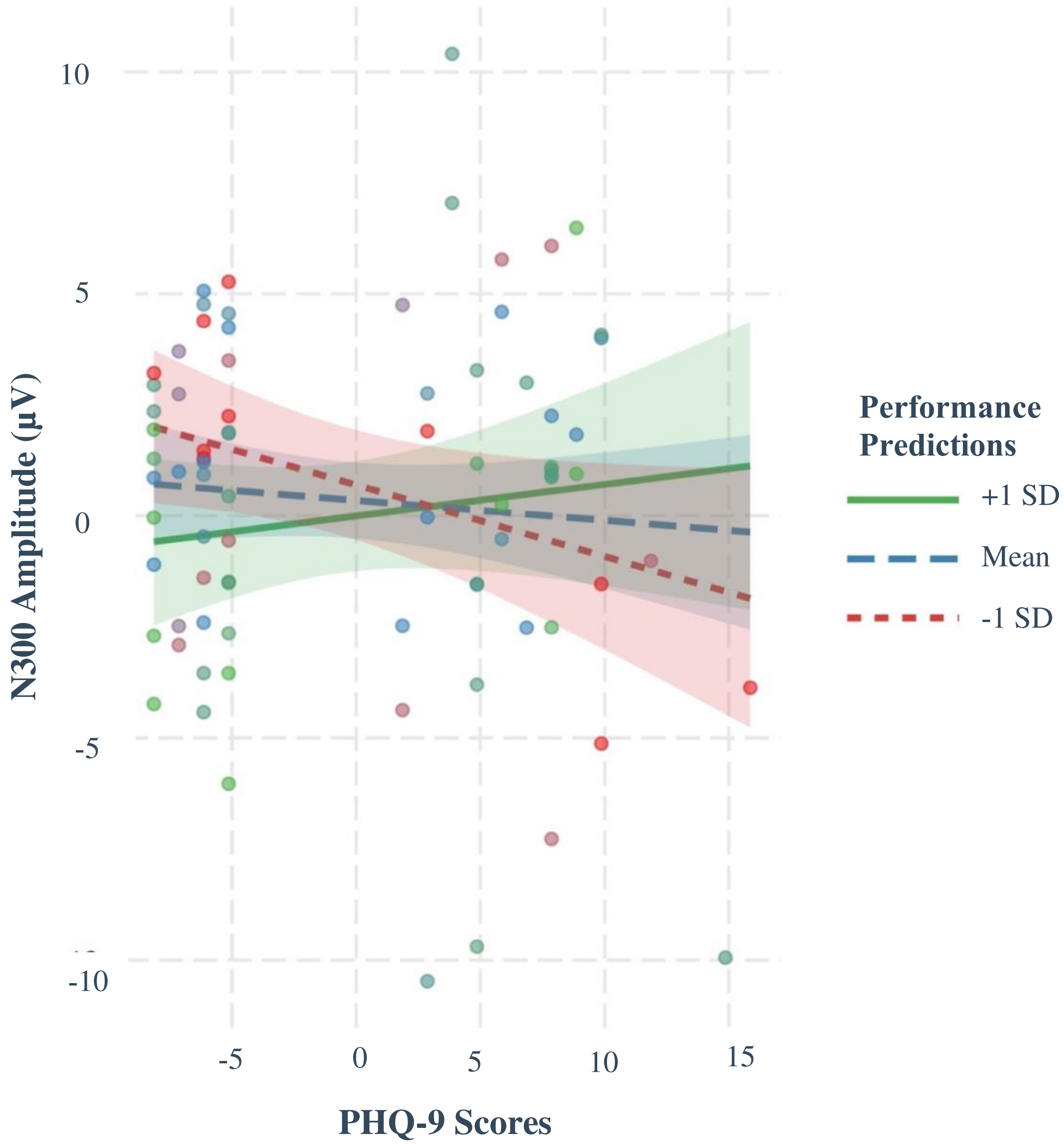


*Figure 5.* Results of Depression Levels Related to the N300 Amplitude Moderated by Performance Predictions. A scatterplot showing that in participants with lower performance predictions, increased depression levels, measured by upper and lower quartile scores from the PHQ-9, predict a larger N300 response. The shaded areas represent 95% confidence intervals.

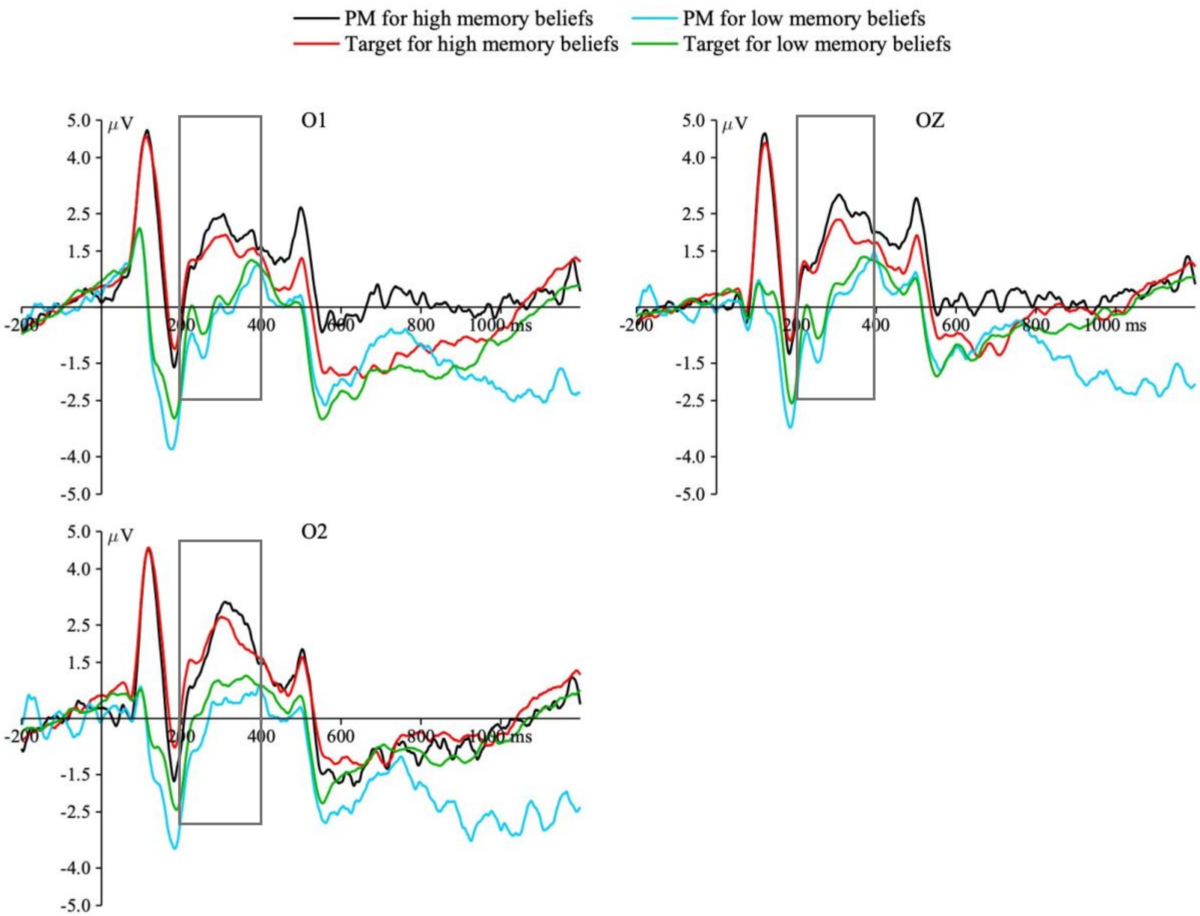



*Figure 6.* Results for High Depression Related to the N300 Amplitude Moderated by PM Beliefs. ERP results for the N300 at electrodes O1, Oz, O2. The N300 is characterized by a brief negative peak 200 – 400 ms after stimulus onset. The neural responses during the PM trials for participants with high depression levels and low PM beliefs were larger (i.e., more negative) than the responses for participants with high depression levels and high PM beliefs. The ERP graph is a useful visualization tool, but it is not intended to reflect group-based analyses for the relationship between depression and the N300 based on metamemory.

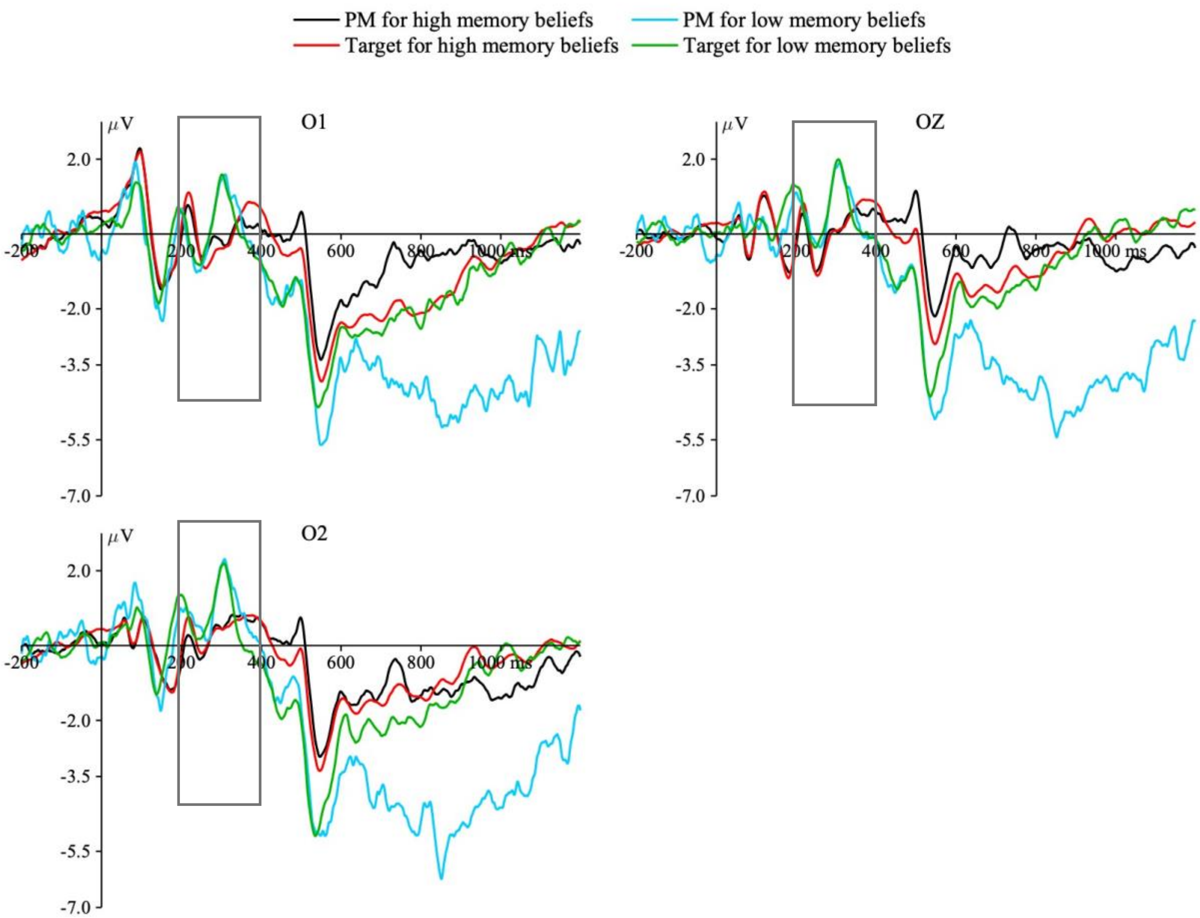



*Figure 7.* Results for Low Depression Related to the N300 Amplitude Moderated by PM Beliefs. ERP results for the N300 at electrodes O1, Oz, O2. The N300 is characterized by a brief negative peak 200 – 400 ms after stimulus onset. The neural responses during the PM trials for participants with low depression levels and low PM beliefs were not different than the responses for participants with low depression levels and high PM beliefs. The ERP graph is a useful visualization tool, but it is not intended to reflect group-based analyses for the relationship between depression and the N300 based on metamemory.

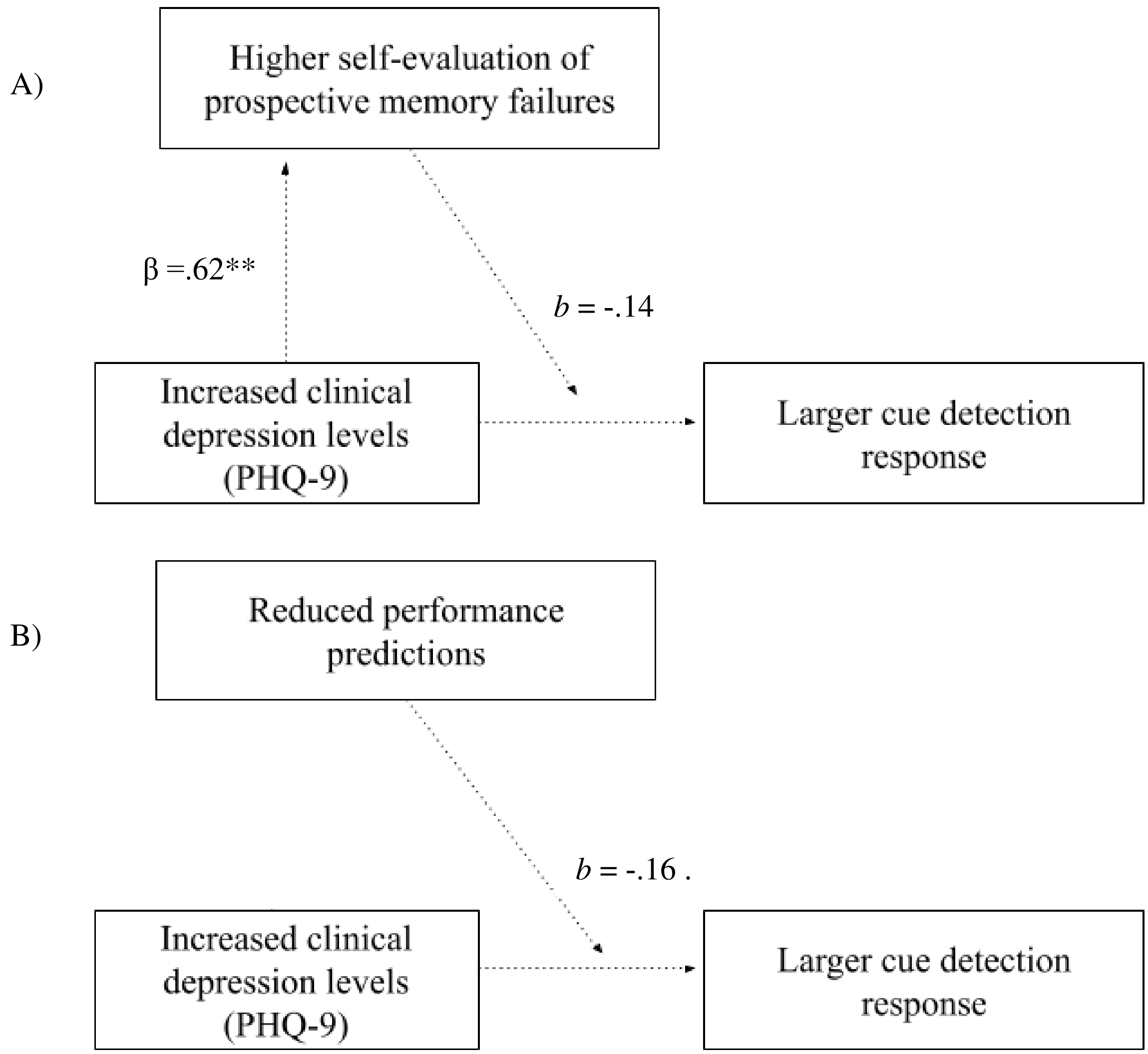



*Figure 8*. Model Relating Depression to Cue Detection with Metamemory Beliefs as the Moderator. A) The relationship between clinically relevant depression levels and cue detection is moderated by PM-related metamemory representations. Participants with increased depression levels demonstrate a larger cue detection response as they also experience higher self-evaluations of PM failures. Overall interaction, $\beta = -.02$, $p = .061$. At +1 SD, $b = -.14$, $p = .15$. Main effect of PHQ-9 on the PRMQ is also represented ($\beta = .62$, $p < .01$). B) The relationship between clinically relevant depression levels and cue detection is moderated by performance predictions. Participants with increased depression levels demonstrate a larger cue detection response as they also report reduced performance predictions for the PM task. Overall interaction, $\beta = .01$, $p = .050$. At -1 *SD*, $b = -.16$, $p = .05$.
. indicates $p < .10$. * indicates $p < .05$. ** indicates $p < .01$

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# CHAPTER 4: EXAMINING UNDERLYING FACTORS FOR DEPRESSION-RELATED IMPAIRMENTS IN PROSPECTIVE MEMORY PERFORMANCE

## 4.1. SUMMARY

The current study examined how depressive symptoms impair prospective memory (PM) in college students by focusing on neural and psychological mechanisms, specifically metamemory beliefs and event-related potential (ERP) components related to cue detection and intention retrieval. Data was analyzed from 80 students with a range of depression symptoms, using both the Center for Epidemiological Studies – Depression Scale and the Patient Health Questionnaire-9 Scale, to assess how depression might relate to PM performance while recording neural activity from an electroencephalogram (EEG). Results revealed that elevated depression levels predicted worse PM accuracy, and exploratory analyses demonstrated metamemory beliefs fully mediated this relationship. Further exploratory findings indicated that cue detection responses moderated the strength of depression on PM performance. Specifically, larger cue detection responses were linked to increased impairments in PM accuracy as depression reports increased. When examining a possible moderated mediation effect, cue detection and metamemory operated independently, suggesting separate pathways through which depression related to PM abilities. These findings provide insight into specific cognitive mechanisms underlying depression-related PM deficits, offering potential strategies for improving goal-oriented behavior in college students with depressive symptoms.

## 4.2. INTRODUCTION

### Prospective Memory and Depression

Depression is a common and potentially debilitating mood disorder (Kessler & Bromet, 2013). Even non-clinical levels of depressive symptomology have been associated with various neural and cognitive differences (McFarland & Vasterling, 2018). Specifically, major depressive disorder has been shown to be related to reductions in volume of the prefrontal cortex, cingulate cortex, and hippocampus (Bremner et al., 2002; Davidson et al., 2002; Hickie et al., 2005). Non-clinical levels of depression are associated with dysregulation of serotonergic, dopaminergic, and cholinergic neurotransmitter systems (Drevets et al., 2008). These depression-related structural and chemical neural differences are further correlated with cognitive abnormalities. For example, planning and problem-solving abilities, attention, and retrospective memory have been shown to be impaired in individuals with increased depression levels (Andersson et al., 2010; Lampe et al., 2004; Simons et al., 2009).

Importantly, these neural networks and cognitive elements also connect to prospective memory (PM) functioning. PM is the ability to create, recognize, and perform future-oriented goals (Einstein & McDaniel, 1990). Attention (Anderson et al., 2017), planning (Shum et al., 2013), and retrospective memory (Einstein & McDaniel, 1990) have all been implicated as important aspects of PM abilities. Further, activity in prefrontal cortices and parahippocampal regions have been associated with accurate PM performance (Burgess et al., 2001). Based on the overlap between the cognitive constituents and neural networks impaired in depression and involved in PM, it is highly likely that PM is also impaired in individuals with depressive symptoms.

While this framework suggests that PM abilities would be disrupted by depression, previous research has indicated various results based on type of PM cue and severity of depression. PM can be time-based or event-based, depending on the type of cue that initiates the future-intended goal. In time-based PM, the goal is signified when a specific time of day occurs. For example, taking medication at 10A.M. would be a time-based PM task. In event-based PM, the goal is triggered when a particular situation or act occurs. For example, stopping in at the grocery store on the drive home from work would be an event-based PM task. Event-based PM may require more cognitive resources than time-based PM, due to the unpredictable nature of the environmental cues (Cona et al., 2012). Based on this idea, event-based PM will be the focus of the current project. Further, there are two cognitive components that underlie PM: cue detection and intention retrieval (Einstein & McDaniel, 1990; West, 2007). Cue detection refers to a person's ability to notice the appropriate environmental prompt to perform their PM goal. Intention retrieval refers to the person then recalling and performing their PM goal. McFarland and Vasterling's (2018) review details how both clinical and non-clinical depression levels may predict event-based PM performance.

For clinical levels of depression, several studies have demonstrated a negative relationship between PM abilities and depression. Altgassen et al. (2009) indicated diminished event-based PM performance for depressed individuals depending on how similar the cue to perform the future-intentioned goal was to the ongoing task. If the cue was more dissimilar to the ongoing task (i.e., non-focal), depressed participants performed worse. This relationship was not seen for cues that were similar to the ongoing task (i.e., focal). Following up on this study, Altgassen et al. (2011) reported decreased focal event-based PM performance for depressed individuals in a task with negative, positive, and neutral emotionally valanced cues. When examining differences within the cue types, there was only a significant difference between the groups for the positive cues: depressed participants performed significantly worse when cued by a positive word in comparison to nondepressed participants. Li et al. (2013) demonstrated impaired non-focal event-based PM performance for depressed college students when there was a fifteen-minute delay between instructions and the task, as opposed to a two-minute delay. Chen et al. (2013) used eye tracking to assess PM abilities and cue detection, but not intention retrieval, in participants with depression. Depressed participants performed worse on the focal event-based PM task than nondepressed participants, and the depressed participants struggled more with cue detection. Further, Li et al. (2014) reported that when depressed and non-depressed participants were told to prioritize the ongoing task, there were no performance differences on the focal event-based PM task. When the participants were told to prioritize the PM task, depressed participants performed significantly worse, suggesting difficulties in directing attentional resources (Li et al., 2014).

For non-clinical levels of depression, studies have suggested more variability in the relationship between PM and depression. Harris (1999) found no relationship between non-focal event-based PM performance and depression in college students. Notably, Harris (1999) did not report the range of depression levels in the study. Livner et al. (2008) also reported no relationship between low severity depression levels and overall non-focal event-based PM performance in older adults, but the authors did attempt to differentiate between cue detection (i.e., the prospective component) and intention retrieval (i.e., the retrospective component) behaviorally. Through this differentiation, they determined that the depressed older adults performed worse on the retrospective components, but not the prospective component of PM (Livner et al., 2008). Lee et al. (2010) also demonstrated no effect on both focal and non-focal event-based PM performance for mild depressive levels in comparison to low or no depressive levels. Marsh et al. (2009) found no relationship between non-focal event-based PM and mild depressive levels. Lastly, Albiński et al. (2012), Arnold et al. (2015), and Bowman et al. (2019) indicated no relationship between focal event-based PM for mild depressive levels in comparison to low or no depressive levels for young adults.

Based on this literature, depression likely has a negative relationship with event-based PM abilities, but only at moderate to severe levels of depression. Also, while it is important to note the type of cue in the task, focal vs. non-focal, the level of depression seems more important to determine a relationship as opposed to cue focality. Further, McFarland and Vasterling's (2018) review stated that depression-related PM deficits are likely explained by issues with attentional resources, maintenance/monitoring of the environment, and retrieval, but they did not discuss the potential roles of cue detection and intention retrieval. While Chen et al. (2013) addressed cue detection, they did not examine intention retrieval. Livner et al. (2008) behaviorally differentiated between the two PM components, but further work must be done to examine the relationship between depression, cue detection, intention retrieval, and behavioral PM performance. Due to the high prevalence of depression, and the importance of PM in successfully completing goals, more research is necessary to understand how moderate and severe levels of depression may predict PM performance.

By thoroughly investigating the role of depression levels in overall PM performance and its cognitive components, researchers could more effectively tailor intervention strategies aimed at remediating PM abilities. Previous work has shown several successful interventions for supporting PM performance in individuals with depression. Huang et al. (2022) found that event-based PM performance improved in individuals with major depressive disorder following working memory and inhibition virtual reality training. Another study indicated improvement in event-based PM performance when individuals with major depressive disorder were trained using a cognitive compensatory strategy, which teaches participants how to effectively implement reminders, notes, and visual imagery to complete PM tasks (Au et al., 2021). Pourjaberi et al. (2023) implemented a cognitive rehabilitation training curriculum which included strengthening attention shifting, attention processing, planning, categorization, problem-solving, memory, and stress regulation. They demonstrated that participants with moderate to severe depression levels reported more positive memory beliefs for their PM performance on the Prospective and Retrospective Memory Questionnaire (PRMQ), although they did not measure objective PM performance (Pourjaberi et al., 2023). Overall, these studies suggest that PM abilities can be repaired and supported in individuals with depression, but the remediation strategies are not necessarily designed specifically for the cognitive nuances of PM. Researchers should continue to examine how depression levels relate to PM performance, cue detection, and intention retrieval, with the potential to expand intervention options and support cognitive well-being.

### *Prospective Memory and Depression in College Students*

Understanding the relationship between PM and depression is especially important for undergraduate students, as depression is highly prevalent among this population, and PM abilities are critical for success in college. According to a 2023 survey from over 530 colleges, 44% of undergraduate students have reported increased levels of depressive symptoms (Healthy Minds Network, 2023). Based on these high reports, potential depression-related impairments of PM could be a widespread issue among college students. Since PM is required for accomplishing a variety of future-intended tasks, it is a necessary cognitive ability for undergraduates to carry out many of their personal, academic, and professional goals. For example, PM skills are employed when a student sets the intention to study for their exam and complete their assignments during their free time, or when they create their class, work, and social schedules, with the plan to attend all events on time. If a breakdown in PM abilities were to occur, college students could see impairments in their academic and professional success, social life, and overall personal well-being, as they may fail to juggle completing and submitting their assignments, going to work on time, or making availability for social events. Based on previous research, moderate to severe levels of depression likely impair PM abilities, although this relationship has not been sufficiently characterized. To help support the success of college students experiencing depression, researchers should thoroughly examine the potential relationship between depressive symptoms and PM performance.

**The Role of ERPs in Depression and Prospective Memory**

PM is comprised of two underlying neurocognitive components: cue detection and intention retrieval. Electroencephalogram/event-related potentials (EEG/ERPs) are excellent tools to measure the two elements of PM, as they can time-lock neural activity associated with a response to a behavioral PM task. With this precise timing, the two components can be extracted and characterized, as has been shown in various pathological and healthy populations (Chen et al., 2015; West et al., 2001; West & Krompinger, 2005; West & Ross-Munroe, 2002). Further, depressive symptoms have been shown to be related to differences in other ERPs, such as the P100 and P300 in response to emotional faces (Li et al., 2023), and the late positive potential during a working memory task (Jin et al., 2022). This work indicates that EEG/ERPs are sensitive to potential depression-related abnormalities. Regarding the components of PM and neurophysiology, cue detection is reflected by the N300. The N300 is demonstrated by a brief negative peak over the occipital–parietal region between 200 and 400 ms after stimulus onset (West et al., 2001). Intention retrieval is reflected by the prospective positivity. The prospective positivity is indicated by a long-lasting positive peak over the parietal region between 500 and 1000 ms after stimulus onset (West et al., 2001).

In this study, ERPs were used to expand upon behavioral studies examining the relationship between behavioral PM and depression, which has not been done in previous work. By incorporating the neurocognitive components of PM and behavioral PM, this study will be able to determine if depression-related variations in cue detection or intention retrieval help explain the relationship between behavioral PM performance and depression levels. While McFarland and Vasterling (2018) applied a five-phase model to PM and depression (i.e., development, maintenance/monitoring, retrieval, inhibition, and execution), their review did not fully incorporate or address cue detection and intention retrieval. Instead, McFarland and Vasterling (2018) stated that depression-related PM deficits may be explained by impairments in the maintenance/monitoring and retrieval phases of PM. The maintenance/monitoring phase is defined by actively engaging and retaining the intended task while searching the environment for the appropriate cue (McFarland & Vasterling, 2018). The retrieval phase is characterized by retrieving the intended goal from one's memory to perform the task when cued (McFarland & Vasterling, 2018).

While cue detection appears to be present in the maintenance/monitoring phase, intention retrieval seems to be more prominently present in both phases. Based on these definitions, previous work may suggest that intention retrieval could be more sensitive to depression levels, ultimately explaining depression-related PM impairments, but this relationship has not been explicitly explored. Employing EEG/ERPs during behavioral PM performance will allow the current study to more thoroughly address if cue detection or intention retrieval plays a driving role in the relationship between PM performance and depression levels.

**The Role of Metamemory and Depression in Prospective Memory**

Another potential driving factor in the relationship between depression and behavioral PM could be metamemory – a form of metacognition involving thoughts, beliefs, and awareness one's memory abilities (Meeks et al., 2007; Huber et al., 2022). Metamemory beliefs likely predict behavioral PM performance (Meeks et al., 2007); Although, depression may be related to changes in metamemory beliefs, and these depression-related changes in metamemory beliefs could interrupt PM abilities (Huber et al., 2022).

Only one study has investigated how depression and metamemory beliefs may interact with overall behavioral PM performance. Da Silva Coelho et al. (2023) examined the relationship between depressive symptoms and metamemory for PM in older adults, and found potential interactions between age, depression levels, and metamemory beliefs. They found that young-older adults (ages 70 to 80) performed better than old-older adults (over the age of 80) on the PM task when metamemory beliefs were low (i.e., more negative), but not when metamemory beliefs were high (i.e., more positive). This result suggests that higher metamemory beliefs may play a protective role in behavioral PM impairments. When incorporating increased depression levels, however, the old-older adults with higher metamemory beliefs performed worse than the young-older adults with higher metamemory beliefs. This finding indicates that depression levels and metamemory beliefs may interact to change the protective aspects of metamemory beliefs for behavioral PM impairments related to aging. While aging was an important factor of this paper that was not examined in the current study, Da Silva Coelho et al.'s

(2023) work demonstrates how metamemory beliefs and depression levels may interact to have varying roles in overall behavioral PM performance.

Importantly, Da Silva Coelho et al. (2023) did not use a metamemory measure specifically for PM, and they did not report whether the metamemory beliefs varied by depression level. Huber et al. (2022) did include both factors while investigating the relationship between depression levels and metamemory for PM in college students. They found that college students with increased depression levels reported significantly more negative metamemory beliefs specifically for PM on the Prospective and Retrospective Memory Questionnaire (PRMQ). While there was no significant relationship between depression levels and behavioral PM performance, or metamemory reports and PM performance for depressed participants, the authors state that these null results could be a function of not having enough participants with severe depressive levels. Further, Huber et al. (2022) focused on whether adults with depression made accurate metamemory predictions, but they did not assess how depression levels and metamemory beliefs may work together to predict PM abilities. Huber et al. (2022) and Da Silva Coelho et al. (2023) provide important background for how metamemory beliefs for PM may be different in individuals with increased depression levels, and how depression and metamemory may work together to change the protective effects of high metamemory beliefs on cognition, but there are still critical gaps in the literature assessing the role of metamemory and depression in PM.

## Statement of Purpose

Altogether, the current literature suggests depression levels may have a negative relationship with behavioral PM abilities, although the driving factors behind this impairment have been largely unexplored. The current study will investigate how the neurocognitive components of PM and metamemory could work together to play varying roles in the relationship between depression and behavioral PM. Study 1 addressed how metamemory may relate to the neurocognitive components of PM; Study 2 investigated how depression may impair the neurocognitive components of PM, and if metamemory beliefs moderate this relationship. The current study will build upon the results of Study 1 and 2 by further examining how the neurocognitive components of PM and metamemory could both play a role in the relationship between depression and behavioral PM performance.

Based on the importance of the neural components of PM and metamemory in behavioral PM performance, and the likelihood that depression relates to both factors and PM abilities, it is possible that these elements work in combination to modify behavioral PM performance. More specifically, it is possible that behavioral PM may be impaired in college students with increased depression, which could be explained by one of the neurocognitive components of PM. Metamemory beliefs could moderate the relationship between depression levels and the neurocognitive components of PM, altering the mediating role of the neurocognitive components in behavioral PM performance and depression. See Figure 1 for a conceptual model of the potential moderated mediation to be examined in the current study.

By testing these possibilities, this study provides a thorough characterization of the psychological, cognitive, and neural components related to behavioral PM performance. These results could provide college students with critical information on how depression levels may impair their goal-directed abilities, the mechanism underlying this impairment, and the importance of their beliefs about their memory abilities. For example, if the study finds that high depression levels are associated with impaired behavioral PM performance, and this relationship is explained by a reduced intention retrieval response, researchers could guide students to protect their PM abilities by focusing on support strategies for recalling their intended goal. Further, if the study finds that metamemory alters the relationship between depression and intention retrieval, such that more positive metamemory beliefs buffer the negative role of depression, this finding suggests that students experiencing depression should also be provided with tools to strengthen their confidence in their own abilities. With this information, college students experiencing depression can work towards enhancing and supporting their future-oriented goals.

**Hypothesis 1**

Previous research suggests that event-based PM is likely impaired with increased levels depression, particularly in moderate to severe levels of depression (McFarland & Vasterling, 2018). Based on this work, I hypothesize that depression levels will negatively predict behavioral event-based PM performance.

**Hypothesis 2**

Due to the importance of the neurocognitive components of PM in the ability to accurately perform behavioral PM (Chen et al., 2015), I hypothesize that larger intention retrieval and cue detection responses, reflected respectively by the prospective positivity and N300, will positively predict behavioral event-based PM performance.

**Hypothesis 3**

Intention retrieval may be more vulnerable to depression levels than cue detection (McFarland & Vasterling, 2018). I hypothesize that intention retrieval, reflected by the prospective positivity, will mediate the relationship between depression levels and behavioral PM performance.

**Hypothesis 4**

Based on previous work suggesting that metamemory could further alter the relationship between depression and PM-related abilities (Da Silva Coelho et al., 2023), I hypothesize that metamemory beliefs will moderate the mediating role of the neurocognitive component in the relationship between depression levels and PM performance.

See Figure 1 for a conceptual model of the proposed moderated mediation. Overall, these behavioral and neural analyses will indicate the degree to which depression is related to behavioral PM performance, and if this relationship can be explained by the neurocognitive components of PM. Further, these results will determine if metamemory beliefs strengthen or diminish the relationship between depression and the neural PM components, which could alter the role of cue detection and/or intention retrieval in PM abilities. The present study will elucidate how depression, metamemory beliefs, and the neural components of PM interact to support or reduce overall behavioral PM skills.

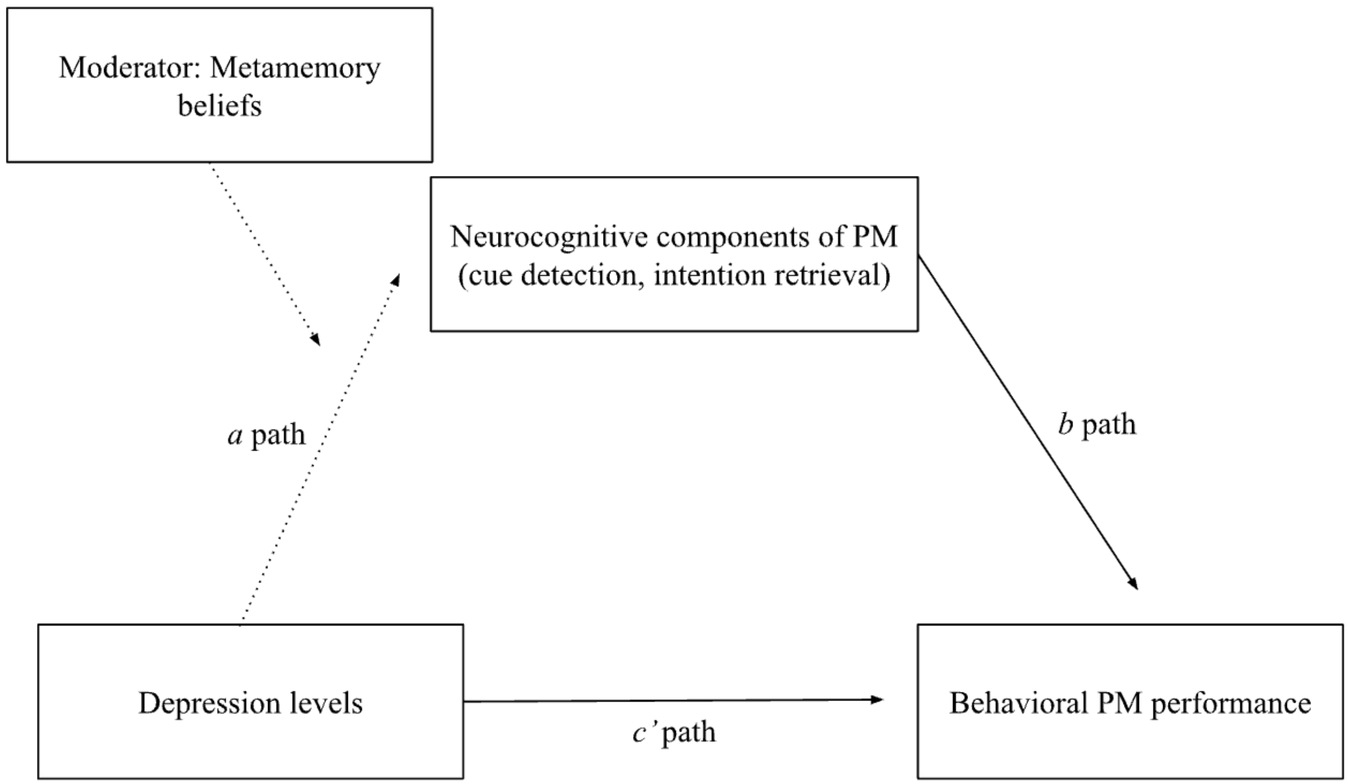



*Figure 1*. Model Relating Depression to Behavioral PM Performance via the Components of PM with Metamemory Beliefs as the Moderator. The mediation model (*a* path, *b* path, *ab*, *c*' path) will be assessed in Study 3. The presence of an interaction effect in Study 2, represented by the dotted lines, could support a moderated effect in the mediation model for Study 3. The moderated mediation is represented by the role of the moderator (metamemory beliefs) on the *a* path of the mediation model.

## 4.3. METHODS

### Participants

Methods for this study were similar to the methods from Studies 1 and 2. I used data from the same 80 participants recruited for Studies 1 and 2. For adequate power (.80) to find medium effects in a mediation analysis using bias-corrected bootstraps, Fritz & MacKinnon (2007) suggest 71 participants. Prior to coming to the lab, potential participants completed a demographics survey assessing biological sex, gender, age, race, ethnicity, handedness, socioeconomic status, and history of epilepsy. Exclusion criteria included being below the age 18, not having normal or corrected hearing and vision, and a history of seizures. Corrected hearing and vision were necessary for participants to receive the instructions and carry out the task. Individuals with a history of epilepsy were excluded due to the irregularity in neural electrical activity associated with seizures, which could lead to irregular EEG readings. The other measures in the survey were not used to exclude participants, instead reported to fully convey the demographic characteristics of the sample.

To ensure variability in depression levels, potential participants also completed the Patient Health Questionnaire-9 (PHQ-9; Kroenke et al., 2001) during the screening process. Students scoring in the upper and lower quartiles of the PHQ-9 scores were invited to participate in the lab portion of the study. The PHQ-9 was used to screen participants into the study since it is comparable to semi-structured diagnostic interviews in sensitivity and specificity for detecting major depressive disorder (Levis et al., 2019).

Ninety-two participants completed the study. Twelve participants were excluded due to not understanding the task, with an accuracy lower than 10% on the PM trials. With these exclusions, there was final *n* of eighty ($M_{age}$=19.45, $SD_{age}$=2.75, 3 left-handed, gender identity: 56 women, 4 gender fluid individuals, 1 transgender woman, 3 transgender men). See Table 1 for the full demographics of the sample.

**General Procedure**

Participants were consented and then completed the following surveys: the Prospective and Retrospective Memory Questionnaire (PRMQ; Smith et al., 2000), the Cognitive Confidence Subscale of the Metacognition Questionnaire (MCQ-30; Cartwright-Hatton & Wells, 1997), and the Center for Epidemiological Studies – Depression Scale (CES-D; Radloff, 1977). The primary psychological measures of the study were the PRMQ, Cognitive Confidence subscale of the MCQ-30, PM task performance predictions, CES-D, and PHQ-9. The PRMQ was utilized due to previous studies successfully using the survey to assess metamemory for PM (Kliegel & Jager, 2006; Smith, 2016; Smith et al., 2011). The MCQ-30 Cognitive Confidence subscale was used based on previous research implementing this survey to measure more general metamemory beliefs with a PM task (Swain et al., 2023). The CES-D was used to ensure the study captured the key symptoms of depression that may pertain to PM based on previous research utilizing this survey to assess metacognition and depression in college students (Soderstrom et al., 2011). This study utilized both the PHQ-9 and CES-D to capture a comprehensive range of depressive symptomatology. The PHQ-9 is particularly effective for identifying clinical levels of major depressive disorder, whereas the CES-D encompasses a wider spectrum and severity of depressive experiences (Amtmann et al., 2014; Levis et al., 2019; Siddaway et al., 2017).

Following completion of the surveys, the participants were administered the EEG cap and provided with task instructions to complete the PM task. After the participants received the instructions of the task and were given the opportunity to ask questions, they provided the researcher with a performance prediction, on a scale from 0% - 100%, for the PM task. This performance prediction was used based on a previous study examining metacognitive abilities and PM performance (Meeks et al., 2007). Upon completion of the task, participants were debriefed and participation in the experiment was documented for course credit/extra credit.

***Measures***

Prospective and Retrospective Memory Questionnaire (PRMQ; Smith et al., 2000): Metamemory of PM performance was quantified as a single continuous variable from adding the item responses of the PM subscale of the PRMQ. A higher score indicated increased reports of perceived memory problems. See Appendix A for a reproduction of the measure, and Study 1 for a more extensive description of the measure.

Cognitive Confidence Subscale of the Metacognitions Questionnaire (MCQ-30; Cartwright-Hatton & Wells, 1997): Cognitive confidence was quantified as a single continuous variable from adding the item responses. Higher scores indicated lower cognitive confidence. See Appendix A for a reproduction of the measure, and Study 1 for a more extensive description of the measure.

Performance prediction for PM task (Meeks et al., 2007): Performance prediction for the PM task was quantified as a single continuous variable. A higher score indicated more confidence in one's memory abilities. See Appendix A for a reproduction of the measure, and Study 1 for a more extensive description of the measure.

Patient Health Questionnaire-9 (PHQ-9; Kroenke et al., 2001): Depression from the PHQ-9 was quantified as a single continuous variable from summing the item responses. A higher score indicated more severe levels of depression. See Appendix A for a reproduction of the measure, and Study 2 for a more extensive description of the measure.

Center for Epidemiological Studies Depression Scale (CES-D; Radloff, 1977): Depression from the CES-D was quantified as a single continuous variable from summing the item responses. A higher score indicated more severe levels of depression. See Appendix A for a reproduction of the measure, and Study 2 for a more extensive description of the measure.

Visual Search PM Task: This event-based, focal task was used to elicit and assess the ERP components of PM (i.e., the N300 for cue detection and the prospective positivity for intention retrieval). The task was created using PsychoPy3 Experiment Builder (v2021.2.3; Peirce et al., 2019) and was adapted from West and Wymbs (2004). It has three essential components: an ongoing visual search task, a cue detection component, and an intention retrieval component. During the ongoing visual search task, participants were shown a target letter in the center of the computer screen, followed by two test letters on the left and right sides of the display. If the target letter was present in the test letters, the participant pressed V with their left index finger. If the target letter was not present in the test letter, the participants pressed B with their right index finger.

The PM components were introduced to the visual search task after the participants completed a block of the isolated visual search task. The letters D and M served as the cue detection components of PM task. If the letters D or M were present in the test letters, the participants needed to remember to select N with their right middle finger. Remembering to select N when prompted with D or M was the intention retrieval component of the PM task. This PM paradigm has been validated in previous research to elicit the desired ERP components (West & Wymbs, 2004). See Study 1 for a more detailed description of the task. See Appendix B for a reproduction of the task stimulus and instructions.

PM performance was quantified as two continuous variables: accuracy and reaction time. Accuracy was calculated by averaging the number of correct prospective-cue trials. Reaction time was calculated by averaging the response times (ms) for the correct prospective-cue trials. A high accuracy score and lower reaction time indicated better PM performance.

**EEG Procedure**

Electroencephalography (EEG) was recorded at a rate of 1000 Hz using SynAmps2/RT 64 Channel system (Curry7, Compumedics NeuroScan, USA) (acquisition bandwidth = 1000 Hz, sampling rate = 1000 Hz) and a 64 electrode Quik-cap Neo Net with sewn-in or affixed to skin via an adhesive patch silver-chloride sintered electrodes (Diameter = 1.5 cm; Compudics USA, Inc. Model: C190). The electrodes are placed in the cap based on the 10-20 electrode placement standard. A .01 Hz high-pass filter and a 100 Hz low-pass filter were used during recordings. Electrode placements followed the Quik-cap 64 system and included all electrodes (Fpz, Fz, Pz, Poz, Oz, Fp1, Fp2, Af3, Af4, F1, F2 F3, F4, F5, F6 F7, F8, F11, F12, Fc1, Fcz, Fc2, Fc3, Fc4 Fc5, Fc6, Ft11, Fc12, C1, Cz, C2, C3, C4, C5, C6, T7, T8, Tp7, Tp8, Cp1, CPz, Cp2, Cp3, Cp4, Cp5, Cp6, P1, P2, P3, P4, P5, P7, P6, P8, Po3, Po4, O1, O2, Po7, Po8, Cb1, Cb2, left mastoid M1, right mastoid M2, VEOU, VEOL, HEOL, HEOR). Eye movements were monitored with electrode placement on the lateral and superior of the left eye for Vertical Electrooculogram (EOG), and the outer corner of each eye for Horizontal EOG. The reference electrode was placed between Cz and CPz. The ground electrode was AFz. During recording, all electrodes were referenced to electrode Cz (Rice et al., 2024).

**EEG/ERP Analyses**

N300: Cue detection was calculated as a single continuous variable measured from the average amplitude (µV) of the neural responses for correct prospective-cue trials between 200 and 400 ms, from electrodes O1, Oz and O2. A larger negative amplitude indicated a stronger N300 response, suggesting a larger cue detection response (Chen et al., 2015; Rice et al., 2024; West & Wymbs, 2004).

Prospective positivity: Intention retrieval was calculated as a single continuous variable measured from the average amplitude (µV) of the neural responses for correct prospective-cue trials between 500 and 1000 ms, from electrodes P3, Pz and P4. A stronger positive amplitude indicated an enhanced prospective positivity response, suggesting a larger intention retrieval response (Chen et al., 2015; Rice et al., 2024; West & Wymbs, 2004).

EEG data were processed in MATLAB (version R2022b) using EEGLAB (version 2024.0) with the ERPLAB plug-in (version 10.04; Lopez-Calderon & Luck, 2014). A 0.1–30 Hz zero-phase-shift bandpass filter was applied. Ocular artifacts were corrected using the Independent Component Analysis feature in EEGLAB. The EEG data were re-referenced to an average reference and trials exceeding a voltage of +/- 100 µV were removed from trials. The ERP epoch included -200 to 1200 ms of activity around stimulus onset (Rice et al., 2024). To analyze the electrode clusters, mean voltages of electrodes O1, Oz, and O2 were averaged to measure the N300. Mean voltages of electrodes P3, Pz, and P4 were averaged to measure the prospective positivity, as has been performed in previous literature (Chen et al., 2015; Groot & Strien, 2019; Zhang et al., 2019).

**Statistical Methods**

To test hypotheses 1 and 2, multiple linear regression analyses were conducted in R (version 4.3.1; R Core Team, 2021) examining associations among depression from the CES-D and PHQ-9, the neurocognitive components (the N300 and the prospective positivity), and PM accuracy and reaction time (RT), with participant age and gender as control variables in the models. Based on previous work demonstrating that depression, ERP components, metamemory, and PM performance may vary with age and gender, all analyses controlled for age and gender (Bowman et al., 2015; Collier Villaume et al., 2023; Guillem & Mograss, 2005; Hertzog et al., 2019; Riess et al., 2016, 2016; Salk et al., 2017; Schnitzspahn & Kliegel, 2009; West, 2011). By controlling for these variables, the current study was able to focus specifically on how metamemory, depression, and the ERPs related to behavioral PM performance, while accounting for potential confounding effects of age and gender. Gender was divided into three categories to include individuals outside of the binary (e.g., man, woman, and transgender + nonbinary) and was dummy coded for the regression analyses (DuBois & Shattuck-Heidorn, 2021).

For the regression models, effect sizes were measured using partial R-squared, calculated from the linear regressions. To obtain effect sizes, R-squared values were calculated for both the full models and reduced models (i.e., excluding the independent variable). Then, the partial R-squared was calculated as the difference between the R-squared values for the full and reduced models, capturing the unique effect size of the independent variables while controlling for age and gender. Exploratory paired samples *t*-test were conducted on the difference between performance predictions and observed accuracy among high and low depressed participants to determine if there was a significant difference between predicted accuracy and observed accuracy based on depression levels. All tests were two tailed ($\alpha = .05$).

### *Mediation Model*

To determine if the ERP components could mediate any potential relationship between depression and PM performance as predicted in hypothesis 3, direct and indirect effects were calculated for a mediation model. In mediation models, the direct effect (*c'*) represents the strength of the relationship between the predictor (X) and the outcome (Y). The *a* path reflects the effect of X on the mediator variable (M), while the *b* path shows the effect of M on Y. The indirect effect (*ab*) quantifies the extent to which M mediates the relationship between X and Y (Edwards & Lambert, 2007). See Figure 2A for a conceptual representation of a basic mediation. According to the Baron and Kenny's (1986)'s mediation casual steps approach, mediation is present if the *c', a*, and *b* paths are significant, and the direct effect (*c'*) is smaller than the total effect (*ab* + *c'*). Larger values for the *c'* and *ab* coefficients indicate stronger direct and indirect effects, respectively. The relationship between X and Y may be fully or partially mediated by M. Full mediation occurs when the direct effect is nonsignificant and the indirect effect is significant, meaning M fully explains the relationship between X and Y. Partial mediation is indicated when both direct and indirect effects are significant, suggesting that while M influences Y, the relationship between X and Y persists without M (Edwards & Lambert, 2007). To test hypothesis 3, depression measures (X) acted as the predictor variables, and PM accuracy or reaction time were the outcome variables (Y). The ERP components (M) were the mediator variables that facilitated the relationship between depression and PM performance. The precise observed variables (i.e., depression measure, ERP components, behavioral measure) used in the models would be determined by significant main effects.

Mediation analyses were performed using the "mediation" package in R, and they followed the mediation casual steps approach (Baron & Kenny, 1986; Edwards & Lambert, 2007; Tingley et al., 2014). To analyze the significant main effect findings, two regression models were developed. The first model examined the mediator (e.g., ERP components) in relation to the independent variable (e.g., depression), while the second model assessed the outcome (e.g., PM performance) based on both the independent variable and the mediator. The results from these two regression models were then used as the primary inputs for the "mediate" function, which calculates the direct, indirect, and total effects. The significance of the indirect effect was determined using a nonparametric bootstrap method with 10,000 random samples.

***Moderated Mediation Model***

To determine if metamemory changes the mediatory role of the ERP components in the relationship between depression and PM performance as predicted by hypothesis 4, an interaction term was introduced to the *a* path in the original mediation model. Adding an interaction term to any path of the mediation model creates a moderated mediation, where the mediating effect of the indirect pathway is moderated by another variable (Baron & Kenny, 1986; Edwards & Lambert, 2007). In a moderated mediation, a moderator (W) is added to the model to assess if the mediation role of M is conditional based on varying levels of W (Hayes & Rockwood, 2020). W can be added to the *a*, *b,* or *c'* paths to examine how the moderator changes the role of M on X and Y (Hayes & Rockwood, 2020).

In Edwards and Lambert's (2007) review of moderated mediation models, they propose a general path analytic framework for combining mediation and moderation, where the moderator is tested on the *a*, *b*, and *c*' pathways to assess a first stage, second stage, and direct effect moderation, respectively. See Figure 2B, 2C, and 2D for a conceptual representation of first stage, second stage, and direct effect moderation models. While hypothesis 4 posits that the moderator, metamemory, would be play an important role on the *a* path (i.e., the first stage), the second stage and direct effect pathways were also assessed. A significant first stage moderator would indicate the relationship between depression (X) and neurocognitive components (M) was moderated by metamemory (W). A significant second stage moderator would indicate that the relationship between the neurocognitive components (M) and PM performance (Y) was moderated by metamemory (W). A significant direct effect moderator would suggest that the relationship between depression (X) and PM performance (Y) was moderated by metamemory (W). Testing for second stage and direct effect moderator models was exploratory, while a first stage moderator would be consistent with hypothesis 4.

To test the moderated mediation proposed in hypothesis 4, interaction models were first tested for each pathway of the mediation model. Interaction analyses were conducted using the “interactions” package in R (Long, 2024). The interaction terms were created by multiplying standardized scores for X (i.e., the independent variable) with standardized scores for W (i.e., the moderator), and this term would be tested in predicting M or Y, depending on the path being tested (i.e., the mediator or dependent variable). The covariates, age and gender, were also included in the interaction models. For significant or marginally significant interaction models, simple slopes analyses were conducted to further explore the nature of the interaction. The slopes characterizing the role of the moderator on the relevant path of the mediation model would be examined at high (+1 standard deviation), average, and low (−1 standard deviation) levels.

Next, the significant or marginally significant interaction effects would be included in the mediation models by adding the interaction term in the appropriate regression pathway for the main inputs of the “mediate” function (Tingley et al., 2014). The significance of the indirect effect was estimated by the nonparametric bootstrap approach (with 10,000 random samplings). If the moderated mediation model demonstrated a different indirect effect than seen in the original mediation model, the conditional indirect effects would be tested by assessing the strength of the indirect affect at high (+1 standard deviation), average, and low levels of the moderator (−1 standard deviation; Hayes, 2017; Hayes & Rockwood, 2020).

### *Calculation of Standard Error*

For the mediation and moderated mediation models, bootstrap standard errors for the estimates were calculated. These bootstrap standard errors reflect the precision of the bootstrapped sample means in estimating the population means. A smaller bootstrap standard error indicates greater accuracy in estimating the population mean, while larger values suggest less accuracy (Efron & Tibshirani, 1986). The standard error values are reported in the tables for each model.

### *Confidence Intervals*

Confidence intervals were calculated and reported for the mediation and moderated mediation models in their respective tables. When the range does not include zero, the effect is considered statistically significant. In this study, 95% confidence intervals (95% CI) were calculated, implying a 95% probability that the true effect size lies within this range (Flechner & Tseng, 2011). Confidence intervals were derived from 1,000 bootstrapped samples, resulting in bias-corrected bootstrapped confidence intervals.

### *Missing Data*

There were no instances of missing data in the sample.

### *Interpretation of Analyses*

To convey the strength and extent of relationships, standardized betas, unstandardized betas, and effect sizes were reported alongside *p*-values. Although *p*-values were used to assess statistical significance, greater emphasis was placed on effect sizes and betas, where applicable, to provide a more nuanced interpretation. While *p*-values help determine the likelihood that findings are due to chance, they do not convey the magnitude of effects and are influenced by sample size (Sullivan & Feinn, 2012). In contrast, standardized betas and effect sizes offer valuable insights into the strength of associations. For the regression and interaction models, standardized betas ($\beta$) specifically capture the strength and direction of relationships (van Ginkel, 2020). In the simple slopes analyses, mediation models, and moderated mediation models, unstandardized beta coefficients ($b$) were calculated, representing the change in the dependent variable for each one-unit increase in the independent variable (Nieminen, 2022). When comparing mediation models with the moderated mediation models, and the conditional indirect effects of the moderated mediation models, the unstandardized betas and $p$-values were compared to assess if including the moderator resulted in differences in significance and strength of the indirect effect.

Partial R-squared ($\eta^2$) were used to assess effect size, reflecting the proportion of variance in the dependent variables explained by the independent variables, after accounting for covariates in the regression and interaction models (Levine & Hullett, 2002; Stoffel et al., 2021). Partial R-squared and standardized beta values will be interpreted as follows: values below .1 indicate a very small effect, values between .1 and .3 represent small effects, values between .3 and .5 indicate medium effects, and values above .5 correspond to large effects (Cohen, 1988). Given the emphasis on effect sizes and betas, the interpretation will prioritize these metrics over $p$-values. However, $p$-values will be reported, with $\alpha = 0.05$ used to indicate statistical significance and $\alpha = 0.10$ to denote marginal significance.

**Exploratory Alternative Models**

The final model for this project, outlined in Figure 1, is contingent on the initially proposed pathways (*a*, *b,* or *c'*) or their interactions being significant. If depression levels do not significantly predict one or both neurocognitive components of PM, if the neurocognitive components do not predict PM accuracy, or if metamemory does not significantly interact with depression and the neurocognitive components, it would not be plausible to test the neurocognitive components of PM as a mediator for the relationship between depression levels and behavioral PM performance. If the originally proposed mediation or moderated mediation models cannot be completed based on the main effects and interaction effects, alternative models will be tested and interpreted. For example, if the interaction models suggest that metamemory may moderate an unexpected pathway of the mediation model, it would be reasonable to examine and interpret a different exploratory moderated mediation.

Further, it may be plausible to assess a different mediator if the ERPs are not found to be significant mediators. While metamemory was proposed as a moderator, if the results reveal metamemory to be significantly related to both PM performance and depression levels, it may be appropriate to assess metamemory beliefs as a mediator. In a model with metamemory as a mediator, the neurocognitive components could play a moderating role on one of the pathways. If applicable, additional exploratory analyses will be conducted to assess which pathway the ERP component may moderate, based on significant interaction models. To assess exploratory alternative models for both the mediation and moderated mediation, additional models were tested as necessary based on the results of the multiple linear regressions and interaction effects.

While not included in the original hypotheses, these exploratory models would be reasonable based on previous literature suggesting that metamemory, depression, and the neurocognitive components are all likely related to changes in PM abilities. Since the current literature does not suggest clear relationships between these variables, it is possible that the cognitive, neural, and psychological factors are interrelated differently than initially proposed. With these proposed and exploratory models, the present study will thoroughly assess the cognitive and psychological factors involved in PM.

## 4.4. RESULTS

### Descriptive Statistics

Table 2 provides descriptive statistics for depression levels, metamemory measures, the N300, prospective positivity, accuracy, RT, gender, and age, as well as zero-order correlations between these variables. Depression measures (CES-D and PHQ-9) showed a strong correlation with each other ($p < .01$). Gender was significantly correlated with metamemory as assessed by the PRMQ ($p < .05$) and with depression ($p < .05$), while age showed no significant correlation with any other variables. The main effects, interactions, mediations, and moderated mediation models were conducted without gender or age as covariates, and the results did not meaningfully change.

Higher CES-D and PHQ-9 scores represent higher depression levels. For the PHQ-9, scores from 0–4 suggest minimal to no depression, 5–9 indicate mild depression, 10–14 indicate moderate depression, 15–19 represent moderately severe depression, and 20–27 indicate severe depression. Based on PHQ-9 scores, 51% of participants reported minimal to no depressive symptoms, 24% reported moderate depression, 21% reported moderately severe depression, and 4% reported severe depression. The mean PHQ-9 score was 8.14, indicating a slight skew towards lower depression levels, although the sample includes participants with high depression scores (see Table 1).

For the CES-D, scores of 21 and above suggest a high risk for severe depression experiences, with possible scores ranging from 0 to 60. Based on CES-D scores, 61% of participants were at high risk for severe depression, while 39% were at low risk. The mean CES-D score was 26.40, indicating generally higher depression symptoms in the sample (see Table 1).

The PRMQ has a range of 8 to 40, with lower scores reflecting more positive beliefs about PM abilities, and higher scores indicating more negative beliefs. The average PRMQ score in this sample was 24, with a range from 9 to 39, showing a balanced distribution without notable skew towards positive or negative PM beliefs (see Table 1).

The Cognitive Confidence scale has a range of 6 to 24, where lower scores reflect more positive beliefs about cognitive abilities, and higher scores suggest more negative beliefs. The sample's average score on this scale was 12, ranging from 6 to 22, showing slight variability with a minor skew toward negative cognitive beliefs (see Table 1).

For the PM task performance prediction scale, the range is 0% to 100%, where lower scores indicate lower confidence, and higher scores indicate greater confidence in task performance. In this sample, the average performance prediction was 71%, with scores ranging from 15% to 100%, suggesting a skew toward higher confidence in task-specific performance (see Table 1).

**Main effects of Depression and Prospective Memory**

The results demonstrated a marginally significant inverse association between PHQ-9 scores and PM accuracy, and a significant inverse association between CES-D scores and PM accuracy ($\beta$ = -.22, $p$ = .054, $\eta^2$ = .048; $\beta$ = -.28, $p$ = .018, $\eta^2$ = .071). See Figure 3. There were no significant association between the PHQ-9, CES-D, and RT ($\beta$ = .01, $p$ = .939, $\eta^2$ = .000; $\beta$ = .16, $p$ = .161, $\eta^2$ = .026). All analyses controlled for age and gender.

**Main effects of ERPs and Prospective Memory**

The results indicated no significant relationships between the N300, accuracy, and RT ($\beta$ = .01, $p$ = .907, $\eta^2$ = .000; $\beta$ = -.00, $p$ = .991, $\eta^2$ = .000). There was a marginally significant positive relationship between the prospective positivity amplitude and accuracy ($\beta$ = .22, $p$ =

.053, $\eta^2 = .048$). There was no significant relationship between the prospective positivity amplitude and RT ($\beta = .02$, $p = .889$, $\eta^2 = .000$). See Figures 4 and 5.

**Performance Predictions and Actual Performance**

Two paired samples *t*-tests were run on the differences between performance predictions and observed accuracy in the high depression and low depression participants. Low depression was categorized as a PHQ-9 score equal to or less than 3. High depression was categorized as a PHQ-9 score equal to or greater than 11. In the low depression group, the average predicted performance score was 70.01% (*SD* = 19.98). The average observed accuracy was 75.88% (*SD* = 19.91). There was no significant difference between performance predictions and actual accuracy ($t(40) = 1.51$, $p = .14$) in the low depression participants.

In the high depression group, the average predicted performance score was 72.56% (*SD* = 14.25). The average observed accuracy was 70.16% (*SD* = 25.89). There was no significant difference between performance predictions and actual accuracy ($t(38) = -.54$, $p = .59$) in the high depression participants.

**Mediation Analyses: ERPs as Mediators**

As described in Study 2, PHQ-9 scores and CES-D scores were not related to prospective positivity amplitude ($\beta = -.09$, $p = .416$, $\eta^2 = .008$; $\beta = -.09$, $p = .461$, $\eta^2 = .007$). PHQ-9 scores and CES-D scores were also not related to N300 amplitude ($\beta = -.12$, $p = .328$, $\eta^2 = .013$; $\beta = -.08$, $p = .508$, $\eta^2 = .006$). Based on the lack of significance between depression and the ERP components (i.e., the *a* path), the proposed mediation could not be run.

## Moderated Mediation Analyses: Metamemory as Moderator

### *First Stage Moderation with Metamemory as Moderator*

While the *a* path for the proposed mediation model was not significant, a first stage moderation with metamemory as the moderator could be possible if there is a significant interaction effect on the *a* path. As described in Study 2, in the model predicting the N300 amplitude, the interaction between the PHQ-9 and the PMRQ was marginally significant ($\beta$ = -.02, $p$ = .061, $\eta^2$ = .046), suggesting that the relationship between the PHQ-9 and N300 may vary as a function of PRMQ scores. The interaction between the PHQ-9 and performance predictions was significant at a trend level when predicting the N300 ($\beta$ = .01, $p$ = .050, $\eta^2$ = .049), indicating that the relationship between the PHQ-9 and N300 varied as a function of performance predictions. The interaction of depression and metamemory did not significantly predict the prospective positivity (all $p$'s > .10).

While the interaction between depression and metamemory on the N300 provides insights on how metamemory may alter the relationship between depression levels and cue detection responses, the null results for the other main effects did not allow for a moderated mediation. Only the prospective positivity was significant with accuracy for the *b* path. Since there were no main or interaction effects of depression, metamemory, and the prospective positivity for the *a* path, and the N300 was not significantly related to accuracy for the *b* path, a first stage moderation model with metamemory as the moderator could not be tested.

### *Second Stage Moderation with Metamemory as Moderator*

Interaction models were analyzed predicting accuracy based on ERP amplitudes and metamemory reports. Only accuracy was examined to represent PM performance, as there were no main effects seen for RT, depression, and the ERPs, demonstrating that it would not be appropriate to include RT in the mediation or moderated mediation models. There were no significant interaction effects for the ERP components (N300 and prospective positivity) and metamemory (PRMQ, Cognitive Confidence, performance predictions) on PM accuracy (all *p'*s > .10). Based on these results, second stage moderation models with metamemory as the moderator for the *b* path were not tested.

#### ***Direct Effect Moderation with Metamemory as Moderator***

Due to the null *b* path for the mediation model and interaction effects, the direct effect moderation model assessing the role of the ERPs and depression on accuracy could not be tested regardless of the role of a moderator on the *c'* path. Thus, no interaction effects were analyzed predicting accuracy based on depression and metamemory.

### **Exploratory Alternative Models**

#### ***Mediation Analyses: Metamemory as Mediator***

The findings of Studies 1 and 2 suggest that metamemory may serve as a mediator in the relationship between depression and accuracy. For the *a* path, Study 2 revealed that PHQ-9 and CES-D scores had a significant positive association with PRMQ scores ($\beta$ =.62, $p$ < .01, $\eta^2$ = .366; $\beta$ = .65, $p$ <.01, $\eta^2$ = .395). Regarding the *b* path, Study 1 demonstrated that PRMQ scores had a significant inverse association with PM accuracy ($\beta$ = -.33, $p$ < .01, $\eta^2$ = .100). Based on these findings, two mediation analyses were conducted to examine how PRMQ scores may explain the relationship between PHQ-9 scores and accuracy, and CES-D scores and accuracy.

The first mediation analysis examined metamemory beliefs for PM, measured by the PRMQ, as the mediator of the marginally significant association between clinical depression levels, assessed via the PHQ-9, and PM accuracy while controlling for age and gender. The results showed that higher depression was significantly indirectly associated with worse PM accuracy (*ab* = -.63 *p* = .017) via heightened PRMQ scores (see Figure 6). Importantly, higher PRMQ scores reflected more negative (i.e., worse) beliefs in PM abilities. The direct effect was not significant (*c'* = -.10 *p* = .798). These results suggest a potential full mediation. See Table 3.

The second mediation analysis examined metamemory beliefs for PM, measured by the PRMQ, as the mediator of the significant association between heightened depression symptomology, assessed via the CES-D, and PM accuracy while controlling for age and gender. The results showed that higher depression was marginally significantly indirectly associated with worse prospective memory (*ab* = -.43, *p* = .065) via heightened PRMQ scores (see Figure 7). The direct effect was not significant (*c'* = -.27, *p* = .503). Mediation analyses were not run for the other measures of metamemory and PM performance (e.g., Cognitive Confidence, performance predictions, RT) because of the null main effects on accuracy and depression. These results point to a potential full mediation. See Table 4.

***Moderated Mediation Analyses: ERPs as Moderator***

**First Stage Moderation with ERPs as Moderator.** Interaction models were analyzed predicting metamemory based on ERP amplitudes and depression levels. Only the PRMQ was examined to characterize metamemory, as only this metamemory measure demonstrated significant main effects with both PM accuracy (*b* path) and depression (*a* path). There were no significant interaction effects for the ERP components (N300 and prospective positivity) and depression (PHQ-9, CES-D) on the PRMQ (all *p'*s > .10). Based on these results, first stage moderation models with ERPs as the moderators were not tested.

**Second Stage Moderation with ERPs as Moderator.** Interaction models were analyzed predicting accuracy based on ERP amplitudes and metamemory reports (See also Second Stage Moderation with Metamemory as Moderator). There were no significant interaction effects for the ERP components (N300 and prospective positivity) and metamemory (PRMQ, Cognitive Confidence, performance predictions) on PM accuracy (all $p$'s > .10). Based on these results, second stage moderation models with ERPs as the moderator were not tested.

**Direct Effect Moderation with ERPs as Moderator.** Interaction models were analyzed predicting accuracy based on depression scores and ERP amplitudes. The prospective positivity amplitude did not significantly moderate the relationship between depression (CES-D, PHQ-9) on accuracy (all $p$'s > .10). Interaction results for the N300 were significant. The N300 amplitude significantly moderated the association of the PHQ-9 and the CES-D on accuracy, suggesting that the relationship between the depression and accuracy varied as a function of N300 amplitudes ($\beta = .26$, $p = .009$, $\eta^2 = .084$; $\beta = .16$, $p = .028$, $\eta^2 = .059$).

Simple slopes analyses for the moderation of the N300 on the PHQ-9 and accuracy association demonstrated that in participants with larger (i.e., more negative) N300 amplitudes (-1 standard deviation), higher PHQ-9 scores predicted lower PM accuracy ($b = -1.59$, $p < .01$). Participants with smaller N300 amplitudes (+1 standard deviation) did not have a significant association between PHQ-9 scores and the accuracy ($b = .40$, $p = .48$). Participants with average N300 responses did not have a significant association between PHQ-9 scores and the accuracy ($b = -.60$, $p = .11$). These results suggested that higher depression levels from the PHQ-9 were associated with worse PM performance in individuals with accentuated N300 responses. See Figure 8 and Tables 5 and 6.

Simple slopes analyses for the moderation of the N300 on the PHQ-9 and accuracy relationship revealed a similar pattern: for participants with larger (i.e., more negative) N300 amplitudes (-1 standard deviation), higher CES-D scores predicted lower PM accuracy ($b = -1.28$, $p = .00$). Participants with smaller N300 amplitudes (+1 standard deviation) did not have a significant association between CES-D scores and the accuracy (*b* = .00, *p* = 1.00). Participants with mean N300 responses also experienced significantly reduced PM accuracy as CES-D scores increased (*b* = -.64, *p* = .03). These results suggested that higher depression levels from the PHQ-9 are associated with worse PM performance in individuals with larger N300 responses. See Figure 9 and Tables 7 and 8.

Based on the significant interaction effects, direct effect moderation models with ERPs as moderators were conducted by incorporating the interaction term into the direct pathway (*c*' path) of the mediation model. Two moderated mediation analyses were conducted to examine how PRMQ scores may explain the relationship between PHQ-9 scores and accuracy, and CES-D scores and accuracy, while also assessing how N300 amplitudes may change the mediatory role of the PRMQ.

The first moderated mediation analysis examined PRMQ as the mediator of the association between the PHQ-9 and accuracy while controlling for age and gender, with the N300 moderating the relationship between the PHQ-9 and accuracy. When incorporating the moderator in the *c*' path, the indirect pathway indicated that higher depression was indirectly associated with worse PM accuracy through heightened PRMQ scores, but this relationship changed from full significance to marginal significance (*ab* = -.51 *p* = .059). The direct effect remained insignificant (*c'* = -.11 *p* = .804). These results indicated that when considering the interaction between the N300 and depression in predicting accuracy, the mediatory role of the PRMQ may be slightly obscured, but it is still an important factor in explaining clinical depression's negative association with PM accuracy. Further testing was performed to elucidate the strength of the mediator at different levels of the moderator. See Table 9.

The second moderated mediation analysis examined PRMQ as the mediator of the association between the CES-D and accuracy while controlling for age and gender, with the N300 moderating the relationship between the PHQ-9 and accuracy. When incorporating the moderator in the *c*' path, the indirect pathway changed from marginal significance to no significance ($ab = -.36$, $p = .139$). The direct effect remained insignificant ($c' = -.29$, $p = .518$). These results suggested that when integrating the amplitude to the N300 into the direct pathway as moderator on the relationship between depression and accuracy, the mediatory role of the PRMQ became unclear. Further analyses were conducted to understand how the mediator behaved at different levels of the moderator. See Table 10.

***Conditional Indirect Effects.*** To assess the nature of the moderated mediation, conditional mediation models were examined at three levels of N300 amplitude, +1 standard deviation, mean, and -1 standard deviation for both models. In order to address issues related to model convergence and rank deficiency, age was removed from the moderated mediation model, leaving only gender as a covariate. Although age was not highly correlated with other predictors or the interaction term, its inclusion led to computational issues, which may have been due to subtle linear dependencies or higher-order interactions with the predictors. After removing age, the model converged successfully, and subsequent analyses did not show further issues with multicollinearity or rank deficiency. To ensure that removing age from the current models still allowed for appropriate comparison with the previous models that controlled for both age and gender, age was also removed from the original regression, interactions, mediation, and moderated mediation models. While *p*-values and standardized beta values shifted slightly, overall patterns of significance and strength of relationships remained consistent. See Tables 11 and 12 for the original (i.e., control for age and gender) and updated (i.e., control for only gender) main effect regression estimates, Tables 13 and 14 for the updated mediation estimates, Tables 15, 16, 17, and 18 for the updated interaction estimate, and Tables 19 and 20 for the updated moderated mediation estimates.

For the moderated mediation model with PHQ-9 as the primary predictor, the indirect effect demonstrated a significant negative association in mediating the negative relationship of depression with accuracy at -1 standard deviation, average, +1 standard deviation of N300 amplitudes ($ab$ = -.63, $p$ = .012, $ab$ = -.63, $p$ = .013, $ab$ = -.63, $p$ = .013). The direct effect remained insignificant at each level (all $p$'s > .10). These results indicate that the mediatory role of the PRMQ is significant and moderately strong at all three tested levels of the N300 moderator in explaining how clinical depression levels negatively predict PM accuracy. See Table 21.

For the moderated mediation model with CES-D as the primary predictor, the indirect effect demonstrated a marginally significant negative association in mediating the negative relationship of depression with accuracy at -1 standard deviation and average N300 amplitudes ($ab$ = -.43, $p$ = .050, $ab$ = -.43, $p$ = .052). At +1 standard deviation of N300 amplitudes, the indirect effect was significant, although the strength of the relationship remained the same ($ab$ = -.43, $p$ = .046). The direct effect remained insignificant at each level (all $p$'s > .10). These results suggest that the mediatory role of the PRMQ is marginally significant with medium strength at every level of the N300 when explaining how reports of depressive symptoms negatively predict PM accuracy. See Table 22.

Importantly for both models, when analyzed at the three levels of the N300, the standardized betas were nearly identical to the mediation models not including the moderator on the $c$' pathway. Altogether, these results reveal that increased reports of PM-related metamemory failures, reflected by the PRMQ, consistently explain how depression may impair PM performance. Further, the interaction effects demonstrated that participants with accentuated N300 responses experienced worse PM accuracy as depression levels increased. When integrating these mediation and moderation effects, the results suggested that cue detection responses, reflected by the N300, slightly shifted the nature of the mediation models, but the conditional indirect effects were consistent and stable across different levels cue detection response. The mediatory role of the PRMQ was resilient to changes in cue detection responses.

## 4.5. DISCUSSION

While the negative effects of depression on cognition have been well documented, the current study implemented EEG/ERPs to provide novel results on how different neural and psychological mechanisms contribute to impaired PM abilities in college students experiencing heightened depression. The findings demonstrate that increased depression levels, both clinically relevant levels of depression and a broader spectrum of depressive symptoms, predicted impaired accuracy in a PM task. Depression was not directly related to cue detection or intention retrieval, and only intention retrieval was positively associated with PM performance. In other words, an accentuated intention retrieval response predicted better PM performance, but this pattern was not seen for cue detection. Based on the null relationships between depression and intention retrieval, and cue detection and PM accuracy, it was implausible for cue detection or intention retrieval to mediate the negative relationship between depression and PM abilities.

Additionally, an interaction likely exists between metamemory and depression in predicting cue detection responses, as college students with more negative metamemory beliefs experienced higher cue detection responses as depression levels increased. See Study 2 for a more in-depth interpretation of this finding. While this moderation provided insights into how metamemory and depression could contribute to cognitive resources placed towards attention abilities, the lack of a basic mediation did not allow for this effect to be incorporated into a moderated mediation. The results did not fully align with hypotheses 2, 3, and 4, but based on the pattern of results of depression, metamemory, and PM performance, exploratory analyses revealed a moderately strong mediation effect: increased depression levels predicted impaired PM performance through more negative (i.e., worse, reduced) metamemory beliefs. Since the indirect effects were significant while the direct effects were insignificant, the results suggested a full mediation, indicating that worse PM-related metamemory beliefs captured the entire mechanism by which depression impaired PM performance.

Further, exploratory moderation analyses demonstrated that at higher levels of cue detection responses (i.e., larger N300 responses), college students performed worse on the PM task as reports of depression increased. When incorporating the moderation effect into the mediation models, it appeared that the moderation shifted the mediatory role of metamemory, but more in-depth analyses revealed that the mediation effect was consistent and moderately strong at low, average, and high cue detection responses. These combined findings indicate that worse metamemory beliefs are a critical psychological factor in understanding how depression levels predict PM deficits, and heightened cue detection responses can further strengthen the negative association between depression levels and PM performance, but these two mechanisms function primarily independent from one another.

Altogether, only hypothesis 1 of the current study was partially supported, as metamemory beliefs and the neurocognitive components respectively mediated and moderated PM accuracy in a nuanced manner different from the initial predictions. Reaction time was not implicated in any of the models. Task-specific performance predictions, more general cognitive confidence, and intention retrieval did not appear to be associated with the relationship between depression and PM abilities. The current study expands upon the literature assessing the relationship between depression and PM performance and may provide important insights into variability observed across studies (Altgassen et al., 2009, 2011; Lee et al., 2010; Y. R. Li et al., 2013, 2014; Livner et al., 2008). Further, these results have important implications for college students with depression seeking to support their goal-direct behaviors.

**Cue Detection as a Moderator for Prospective Memory**

Cue detection played an important role in exacerbating depression-related PM impairments. While depression levels were generally related to poor PM performance, this relationship was especially prominent for college students with larger cue detection responses. In contrast, heightened intention retrieval abilities may generally predict better performance on the PM task. Since there were no main effects or interactions effects involving depression, intention retrieval, and PM abilities, these results suggested that college students experiencing depression were likely allocating their cognitive resources more towards monitoring the environment for the cue, inadvertently neglecting the processes that support successful PM performance. Despite the effect sizes for these relationships being small, cue detection acted as a consistent moderator across both depression measures in predicting PM abilities.

While prior research suggests that increased cue detection should enhance PM performance (West et al., 2001), the findings of the current study reveal a depression-specific pattern where higher cue detection responses predicted worse PM outcomes as depression levels increased, likely due to attentional misallocation. The current study suggests that depression levels may disrupt the attentional processes usually required for successful PM, and students with depression may be experiencing a misdirection of cognitive resources that is further impairing their PM abilities. Depression-related attentional biases demonstrated in previous literature, and seen in the current study, likely do not support PM performance (Fuseda et al., 2022; Keller et al., 2019; Li et al., 2014). The moderating role of a larger cue detection response predicting worse PM performance in college students with depression contributes to the literature describing an ineffective allocation of cognitive resources in participants experiencing depression, particularly for attention-related skills.

More specifically, these findings are consistent with Chen et al.'s (2013) results that adults with increased depression levels perform worse on an event-based PM task and that they may be directing more cognitive resources ineffectively towards the attention-related aspect of the goal-directed task (i.e., cue detection) based on their patterns of eye tracking. Further, Li et al. (2014) suggested that adults with depression perform worse on a PM tasks due to difficulties in guiding attentional resources, as their study manipulated how participants were informed to guide their attention during the task. When participants with depression were instructed to focus on the PM task over the ongoing task, they demonstrated impaired PM performance in comparison to non-depressed participants, who demonstrated improved PM skills (Li et al., 2014). These findings suggest that while healthy adults are able to effectively allocate their attention resources to enhance their PM performance, individuals with depression do not demonstrate efficiency in directing attentional abilities in a manner that supports PM skills, even though they may be exerting more cognitive effort towards attention (Chen et al., 2013; Li et al., 2014). The current results expand on these studies by explicitly comparing both cue detection and intention retrieval using EEG/ERPs and demonstrating how variations in attention guidance further impaired PM abilities for college students with depression, suggesting an inefficient allocation of cognitive resources.

Interestingly, reduced cue detection responses were not associated with impaired PM accuracy as depression levels increased. These findings suggest that placing less cognitive effort towards monitoring the environment for goal-related cues may be protective against depression-related impairments in goal-directed behaviors. When cue detection responses were smaller, students with depression may have more of an even distribution of cognitive resources aimed at completing their future-oriented goal. These findings highlight that when students allocate more cognitive resources towards cue detection, they are inefficiently directing their cognitive effort in ways that ultimately hinder their ability to complete intended goals, revealing a depression-specific pattern in PM performance.

Importantly, the initial hypotheses proposed the neurocognitive components of PM to be a mediator of the relationship between depression and PM abilities, but the results revealed cue detection to be a moderator instead. Cue detection and/or intention retrieval were proposed to be mediators based on the involvement of both these components in successful PM performance (West et al., 2001). It would be reasonable to think that an impairment in PM abilities may be explained by a deficit in one or both neurocognitive factors. In contrast, changes in these components did not explain depression-related PM impairments, but instead strengthened the negative relationship. While different from the initial framework of the study, these findings provide novel, valuable insights into how the neurocognitive mechanisms underlying PM, particularly cue detection, may lead to worse PM abilities for students with increasing levels of depression.

Since an enhanced intention retrieval response predicted better PM performance across the sample, it is possible that when students with depression were focusing on monitoring the environment for the cue, they were doing so at the detriment of maintaining the intended goal in their mind, ultimately resulting in worse PM performance. In other words, when college students with depression were guiding more cognitive resources towards cue detection, they were likely focusing their attention in a manner that did not support successful goal completion. Since depression is characterized by issues with concentration (Chand & Arif, 2024), it is possible that college students with depression attempted to overcompensate by placing more effort towards the monitoring and attention aspects of the PM goal, but this attempt was not efficient in supporting goal completion, and it ultimately further reduced PM performance.

While the initial hypotheses of the study emphasized the potential importance of intention retrieval in depression-related PM impairments, the significance of cue detection provides new insights into the distinct roles of intention retrieval and cue detection for students experiencing depression. The hypotheses were formed from the idea that depression-related PM struggles may be negatively related to the maintenance/monitoring *and* retrieval phases of PM, and both of these phases are implicated in intention retrieval, while only the maintenance/monitoring phase is involved in cue detection (McFarland & Vasterling, 2018). Instead, the results of the current study suggest that the maintenance/monitoring phase of PM is primarily involved in goal-directed challenges for students with depression, reflected by the moderating role of cue detection.

**The Mediatory Role of Metamemory**

Metamemory beliefs provide valuable insights on the mechanism driving the negative relationship between depression and PM performance. With both depression measures, metamemory beliefs as related to PM explained how increasing levels of depression may have harmed PM abilities. This mediation was more robust in the model with clinically relevant levels of depression (i.e., PHQ-9), but there was still a medium effect size and marginal significance for the model including a broader spectrum of depression symptoms (i.e., CES-D). While different from the original hypotheses of the study, these findings expand previous research demonstrating that metamemory may be an important factor in understand PM impairments.

Although the field currently lacks thorough research examining PM performance, cue detection, intention retrieval, metamemory, and depression, Da Silva Coelho et al.'s (2023) demonstrated how metamemory may act as a buffer for age-related PM challenges for older adults with low levels of depression. While this finding was originally interpreted to posit metamemory as a moderator, Da Silva Coelho et al. (2023) also suggested that metamemory beliefs could help explain cognitive impairments related to both depression and aging. The results of the current study are consistent with metamemory playing an explanatory role. Further, Karazsia and Berlin (2018) described how a mediator can eventually become a moderator with time, which aligns with metamemory acting as a mediator in the relationship between depression and PM performance for younger adults, but potentially evolving to become a moderator for older adults. Instead of altering the relationship between PM skills and depression, the current findings reveal metamemory to explain the relationship between PM abilities and depression. The exploratory analyses of this study highlight valuable insights on how metamemory may underly depression-specific challenges in goal-directed behaviors, broadening prior research on how depression and metamemory may both relate to PM performance.

Further, the findings of the current study provide a new perspective on Huber et al.'s (2022) results. Huber et al. (2022) did not find that depression levels negatively predicted PM performance, or that depression levels altered the relationship between metamemory beliefs and PM performance, but the authors described how the null relationships could have been related to participants not reporting severe levels of depression. The current study used the PHQ-9 to ensure that some participants were reporting moderately severe to severe levels of depression. The CES-D scores also reflected critically high reports of depressive experiences across a more detailed range of symptoms. Through this methodology, the findings of the study support the idea that future-oriented, goal-directed behaviors were impaired at higher levels of depression, and PM-related metamemory played a significant role in PM challenges for students with severe depression. Additionally, Huber et al. (2022) demonstrated that depressed and non-depressed participants were not different in their perceived PM abilities (i.e., metamemory beliefs for PM) and their actual PM abilities, which aligned with the exploratory findings. While Huber et al. (2022) and Da Silva Coelho et al. (2023) suggested that metamemory and depression could potentially work together to contribute to PM performance, the exploratory findings of the study demonstrated how worse PM-related metamemory beliefs act as a mechanism for the negative relationship between PM skills and heightened depression levels.

Instead of one of the neurocognitive components of PM explaining the role of depression in predicting impaired PM as initially proposed, metamemory beliefs, specifically related to PM, were found to be the driving force. This relationship could be present due to issues with concentration and feelings of worthlessness acting as key symptoms that define depression (Chand & Arif, 2024). The more negative metamemory beliefs seen in students with depression may be a function of experiences with these symptoms; college students with high levels of depression may experience challenges with concentration and low self-worth, resulting in them reporting worse PM-related metamemory beliefs, and ultimately explaining why metamemory evaluations fully mediate the relationship between depression and PM performance.

**Cue Detection and Metamemory to Understand Depression-Specific Impairments**

While both cue detection and metamemory beliefs contributed to depression-specific PM impairments, these two factors did not appear to modulate the roles of each other. Instead, the mediation capacity of metamemory beliefs remained stable across all levels of the moderation of cue detection on depression and PM performance, for both clinically relevant levels of depression (i.e., PHQ-9) and high levels of specific depressive symptoms (i.e., CES-D). These findings have important implications for the distinct and nuanced importance of both cue detection and metamemory beliefs in contributing to and understanding how PM abilities may be challenged as depression levels increase. If students experiencing depression wish to support their PM skills, they could focus on either factor by addressing the mediatory role of negative metamemory beliefs, or the moderating role of misallocating cognitive resources towards cue detection.

The mediation appeared to be slightly stronger for the PHQ-9 than the CES-D, as the model with the PHQ-9 demonstrated full significance and larger effect sizes, while the model with the CES-D only reached marginal significance and smaller effect sizes. When including cue detection as a moderator into the mediation models, the role of metamemory beliefs appeared to be slightly weakened, but the conditional indirect mediation effects for high, average, and low levels of cue detection responses provided further insights on the models. It is possible that the reduced indirect effect of the overall moderated mediation models was observed initially because the mediated relationship was too variable across the full range of cue detection responses, obscuring the overall mediation effect. Examining the mediation effect at the three distinct levels of cue detection responses allowed more consistent and robust patterns to be elucidated. Across all levels of cue detection responses, the indirect effects of metamemory beliefs for the relationship between depression levels and PM performance remained significant or marginally significant, with medium to moderate effect sizes. The direct effects for both models consistently indicated no significance, suggesting full mediation of metamemory beliefs for both models, regardless of cue detection responses.

Altogether, while a moderated mediation was proposed to assess if the negative role of depression-related PM impairments could be explained, and if the mediation was strengthened or weakened under certain conditions, the results reveal a relatively stable and reliable mediatory effect of metamemory beliefs, resilient to changes in cue detections responses. Introducing cue detection as a moderator did not introduce much variability in the strength of the mediation. It is important to consider how both cue detection and metamemory beliefs may be contributing to PM deficits for students experiencing depression, but these relationships should not be assumed to alter each other.

If a college student experiencing depression hopes to improve their future-oriented goal direction behaviors, they could do so by addressing either pathway. For example, they could aim to improve their PM-related metamemory beliefs by believing they can be successful in completing their goal. By reducing the level of negative metamemory beliefs, they may be able to strengthen their PM abilities. Further, they could work to distribute their cognitive resources more evenly between the components of the PM goal, both monitoring the cue for the environment and maintaining the goal in their mind. This strategy could help to correct the overcompensation and misallocation of effort towards cue detection. College students with high levels of depression have options regarding how they can strengthen their PM skills, ultimately giving them flexibility and variability in how they can support their academic, cognitive, and personal well-being.

**Limitations**

It is critical to interpret the results of the current study cautiously, as there are several important limitations. First, this study was cross-sectional, limiting the ability to make causal conclusions. While the interpretations assume depression to be casual in predicting impaired PM performance, with cue detection moderating and metamemory explaining the casual pathway, it is possible that the directionality of these relationships could be switched. For example, depression could act as a moderator between cue detection and PM performance, and poor metamemory beliefs could predict high depression levels. These relationships could also be reciprocal. A true experimental or longitudinal study should be performed to support these findings and the proposed directionality of these relationships. On a related note, the mediation and interaction effects of this study were found as exploratory analyses. Future studies should re-examine these findings with the current models as a priori hypotheses, as opposed to exploratory results.

Second, while the PHQ-9 scale scores reflect a relatively even distribution of high and low depression levels, the CES-D scale scores suggest a skew towards higher depression experiences. This bias could be due to the ability of the CES-D to capture a broader range of depressive symptoms that the PHQ-9, the latter of which is a relatively short measure based on DSM-V criteria for depression. Thus, students who report little-to-no depression levels on the PHQ-9 could still score high on the CES-D. Previous researchers assessing the validity of the CES-D have suggested that while the measure is sensitive and reliable for detecting depressive experiences, if the CES-D is used solely to assess depression levels, it can result in more false positives for severe levels of depression (Jiang et al., 2019; Shean & Baldwin, 2008; Vilagut et al., 2016). By including both the CES-D and PHQ-9, this study captures a more nuanced understanding of depression, with the CES-D highlighting a broader range of depressive experiences and the PHQ-9 offering more diagnostic-relevant specificity.

Third, it is important to note a potential issue with multiple statistical tests performed in this study, as performing multiple tests in this manner could inflate the possibility of type-one errors (i.e., false positives). A family-wise error correction was not performed due to each finding conceptualized as an individual inference with a unique and distinct interpretation. While the hypotheses provided general proposals on how the variables may work together, each finding was interpreted individually, with the metamemory measures, depression measures, and PM neural and behavioral measures assessed as distinct latent concepts, each representing a different aspect of the psychological and cognitive phenomena. One significant test out of many negative tests was not used to fully support or disprove one or multiple hypotheses, but instead each significant and nonsignificant test was used to describe specific aspects of the proposed relationships. Interpreting the findings in this conservative manner allowed the hypotheses to be expanded upon and parsed with important nuances. While the findings should still be interpreted with caution, this style of interpretation does not require correction for multiple testing (Rubin, 2024).

Fourth, the moderated mediation methodology followed Edwards and Lambert's (2007) conceptualization of a general analytic framework for moderated path analyses. Edwards and Lamberts (2007) described more moderated path models that could be examined, which test to see if multiple pathways of the mediation model are moderated simultaneously (e.g., the *a* and *b* pathways, the *b* and *c'* pathways, and *a* and *c*' pathways, and *a, b,* and *c'* pathways). The present study did not test all these possibilities, as the aim was to examine the isolated role of the moderator on the mediation pathway based on the interaction model findings, but future studies could expand on this work by testing the effect of the moderator on multiple integrated pathways.

Fifth, the neural framework of depression and PM described in the introduction and examined in the current study focuses on frontal circuitry, which aligns with the attentional and top-down processes necessary for the computerized PM task in the current study (Chen et al., 2013; Keller et al., 2019). Importantly, more real world, long-term PM goals, such as remembering to attend class on time, and remembering to complete and submit assignments as necessary, may rely on hippocampal regions related to episodic memory. PM likely involves connections between the prefrontal cortex and the hippocampus, as the prefrontal cortex can facilitate active maintenance and contextualization of the PM cue and goal, while the hippocampus can assist in forming associations between the cue and goal that will guide behavior to appropriately perform the PM task (Brandimonte et al., 2014). Further, previous work has demonstrated a cortical and medial prefrontal cortex-hippocampus connection during top-down attentional tasks and decision-making processes, as well as depression-related reductions in the areas (Belleau et al., 2019; Keller et al., 2019; Yu & Frank, 2015).

These connections could be relevant to the current study, as the current findings indicated a moderating role of the top-down attentional component involved in PM, cue detection. It is not a strength of EEG/ERPs to assess subcortical circuity, therefore limiting this study's ability to examine how hippocampal regions may be involved in the current findings. Since prefrontal cortex and hippocampal differences are implicated in PM abilities and depression (Belleau et al., 2019; Brandimonte et al., 2014; Bremner et al., 2002; Davidson et al., 2002; Hickie et al., 2005), continued work should be established that examines how depression impairs more long-term forms of PM involving the hippocampus by employing neuroimaging techniques that can assess subcortical regions, and the connections between the prefrontal cortex and hippocampus during a PM task (e.g., fMRI).

Sixth, and finally, it is important to note that while the standardized betas indicated medium to moderate effect sizes, the partial R-squared demonstrated very small effect sizes. These patterns suggest that while the relationships are consistent, they only explain a small amount of variance in the PM performance. There are likely other cognitive, neural, and psychological factors not captured in the present study that contribute to PM skills. Employing time-based, non-focal and/or more ecological tasks could help elucidate these various components. Future studies should also seek to gather data from a more equal distribution of genders, racial identities, and socioeconomic status to more thoroughly assess how these societal factors are related to depression, metamemory, cue detection, intention retrieval, and PM performance.

**Future Directions and Conclusions**

Overall, the findings of the current study reveal multiple layers of complexity in depression-related impairments for PM. Worse PM-related metamemory beliefs explain depression's negative role in PM abilities, for both potential clinically diagnosable levels of depression (i.e., PHQ-9) and a broader range of depression symptoms (i.e., CES-D). Further, the impairing role of depression on PM performance is accentuated in students with larger cue detection responses. The mediatory role of metamemory beliefs and moderating role of cue detection work independently from each other, with the full mediation remaining consistent in strength, direction, and significance across different levels of cue detection responses. The PHQ-9 may capture dimensions of depressive symptoms that have a slightly more robust relationship with metamemory and cue detection when predicting PM abilities in comparison to the CES-D, indicated by slightly larger effect sizes, but both depression measures demonstrate relatively stable and comparable main effects, interactions, and mediations.

These findings suggest that there are specific aspects of depressive symptoms that may be impairing PM performance, and students with depression could be inadvertently implementing ineffective coping mechanisms when trying to perform their goals. This study can provide students with important information on how to support their future-oriented goal abilities. For example, if a college student is in a period of increased depression, they may find themselves experiencing trouble concentrating and increased feelings of worthlessness, resulting in failures to carry out their PM goals necessary to be successful in class. To combat these challenges, they could aim to support their PM abilities by addressing their self-worth. By focusing on increasing their sense of confidence in their cognition, memory, and goal-related abilities, they could see real-world improvements in their PM performance, as worse metamemory beliefs largely contribute to the negative role of depression in PM skills.

Further, they could aim to more evenly distribute their concentration and attention towards other useful aspects of their future-oriented goal. In the computerized PM task, the results demonstrated an overcompensation of cognitive effort towards monitoring the environment for the cue, potentially at the detriment of remembering the intended goal. In a real-world context, students with depression may be misallocating their concentration, spending excessive time planning, or closely monitoring their progress. These cognitive patterns could contribute to negative rumination and overthinking, ultimately distracting students and impairing their abilities to perform their goals when necessary. Students with depression could benefit from a more balanced approach by shifting some of their mental energy from over-monitoring towards clear, intentional focus on the goal. Similarly, students could purposefully place detailed, explicit reminders of their goal to draw their attention back to the intended action in case they begin to ineffectively cope with excessive monitoring and rumination. Through these tactics, college students with increased depression levels could strengthen their behavioral PM performance, increasing their likelihood of academic and personal success.

This study also expands on previous work demonstrating a variable relationship between depression and PM abilities, supporting the idea that depression is related to PM performance at severe levels of depression, but not necessarily at medium levels. The findings could also explain how metamemory beliefs and cue detection responses vary across studies, as some samples may have unintentionally displayed patterns of cue detection or metamemory that could have concealed the negative role of depressive symptoms on PM performance. Future studies should investigate this possibility by experimentally manipulating metamemory beliefs and the allocation of cognitive resources towards attention to see if different levels of these components shift the overall depression-specific PM relationship. This line of research would also support potential intervention strategies that could be used to strengthen PM skills in college students with depression.

Additionally, while briefly mentioned previously, future work should longitudinally assess how metamemory and cue detection relate to depression-specific PM impairments to examine if metamemory beliefs could become a moderator, as proposed by previous researchers suggesting that mediators can become moderators over time (Karazsia & Berlin, 2018). A longitudinal study would also assess if cue detection and intention retrieval responses change with age, providing further insights on how these neurocognitive components contribute to PM performance in younger and older adults experiencing depression. Since depression is also highly prevalent and debilitating in older adults (Szymkowicz et al., 2023), this line of work could help support cognitive and emotional well-being throughout the lifespan.

Finally, future studies should employ a factor analysis or structured equation modeling (SEM) to examine if there are specific aspects of depression symptomology or metamemory beliefs that most predict and explain PM performance. These analyses would also confirm the interpretation of the current findings that specific aspects of depression (e.g., lack of self-worth, issues with concentration) are the driving forces behind the presently observed relationships. In conclusion, the current study provides evidence that depression levels impair PM performance via negative metamemory beliefs, and accentuated cue detection responses strengthen the negative role of depression on PM abilities. The mediatory effects of metamemory beliefs are resilient to changes in cue detection. See Figure 10 for a conceptual model of these two relationships. With this knowledge, college students experiencing depression can better understand the cognitive, neural, and psychological factors contributing to impairments in their goal-oriented skills. By using these findings to implement support strategies and enhance their PM-related abilities, students with depression can experience greater academic and personal success, facilitating improved well-being and quality of life.

**TABLE 1**

*Descriptive statistics*

| Variable Name | *n* | Percent | Mean | Standard Deviation | Standard Error | Min. | Max. | Range |
|---|---|---|---|---|---|---|---|---|
| Age | - | - | 19.45 | 2.75 | .31 | 18 | 36 | 18 |
| Gender Identity | | | - | - | - | - | - | - |
| Man | 16 | 20.00 | | | | | | |
| Woman | 56 | 70.00 | | | | | | |
| Transgender Man | 3 | 3.75 | | | | | | |
| Transgender Woman | 1 | 1.25 | | | | | | |
| Gender Fluid | 4 | 5.00 | | | | | | |
| Race | | | - | - | - | - | - | - |
| White | 71 | 88.75 | | | | | | |
| Black or African American | 1 | 1.25 | | | | | | |
| Asian | 1 | 1.25 | | | | | | |
| Native American or Alaska Native | 1 | 1.25 | | | | | | |
| Native Hawaiian or Other Pacific Islander/White | 1 | 1.25 | | | | | | |
| Native American or Alaska Native/Black or African American | 1 | 1.75 | | | | | | |
| Do not wish to respond | 3 | 3.75 | | | | | | |
| Ethnicity | | | - | - | - | - | - | - |
| Not Hispanic of Latinx | 65 | 81.25 | | | | | | |
| Hispanic or Latinx | 14 | 17.5 | | | | | | |
| Do not wish to respond | 1 | 1.25 | | | | | | |
| Average Years of Parental Education (Socioeconomic Status) | - | - | 15.49 | 3.57 | .40 | 3 | 22 | 19 |
| PRMQ Score | - | - | 24.31 | 6.94 | .78 | 9 | 39 | 30 |
| Cognitive Confidence Score | - | - | 11.54 | 4.02 | .45 | 6 | 22 | 16 |
| Prediction Performance (%) | - | - | 71.30 | 17.36 | 1.94 | 15 | 100 | 85 |
| Accuracy | - | - | 73.09 | 23.05 | 2.58 | 11.11 | 98.61 | 87.50 |
| Reaction Time (ms) | - | - | 1005. | 274.52 | 30.69 | 282.68 | 2093.87 | 1811.1 |
| PHQ-9 | - | - | 5 | 7.04 | .79 | 0 | 24 | 9 |
| CES-D | - | - | 8.14 | 9 | 1.01 | 15 | 48 | 24 |
| | | | 26.40 | | | | | 33 |

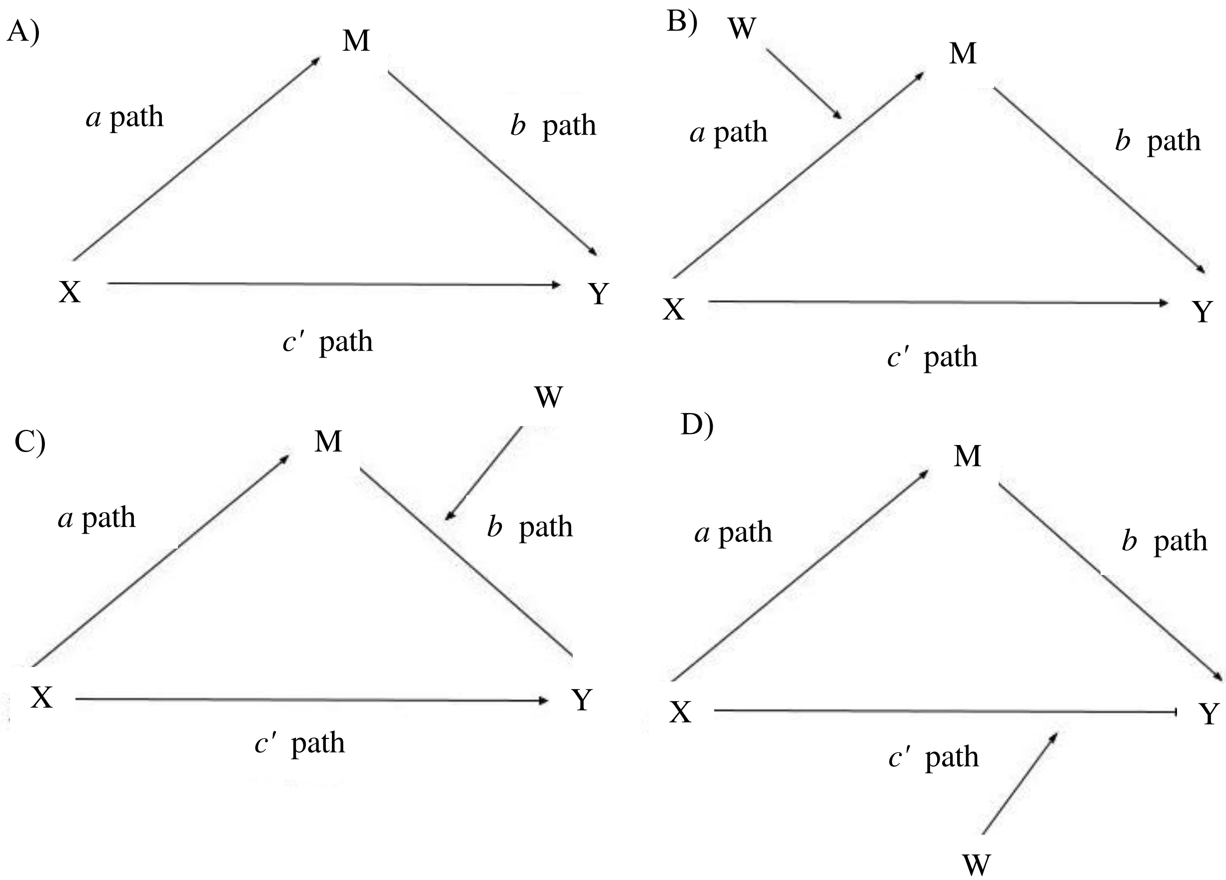



*Figure 2.* Conceptual representations of a A) basic mediation, B) first stage moderated mediation, C) second stage moderated mediation, D) direct effect moderated mediation (Edwards & Lambert, 2007). X is the predictor, M is the mediator, Y is the outcome variable, and W is the moderator.

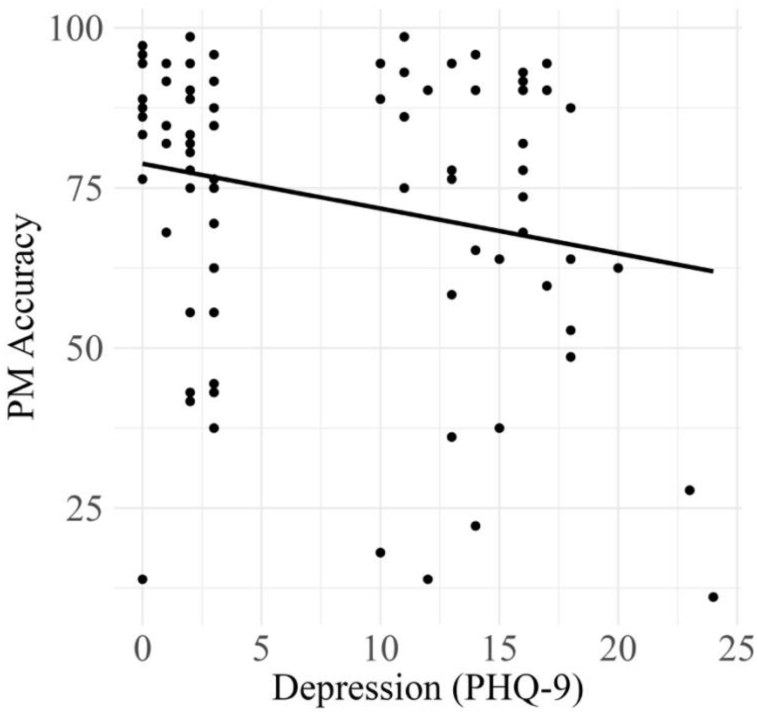
**TABLE 2**

*Means, standard deviations, and correlations with confidence intervals*

| Variable | *N* | *M* | *SD* | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. Accuracy | 80 | 73.09 | 23.05 | | | | | | | | | |
| 2. Reaction Time | 80 | 1005.50 | 274.52 | .08 | | | | | | | | |
| | | | | [-.14, .30] | | | | | | | | |
| 3. Prospective Positivity | 80 | 1.93 | 1.93 | .22* | .01 | | | | | | | |
| | | | | [.00, .42] | [-.21, .23] | | | | | | | |
| 4. N300 | 80 | 0.35 | 3.90 | .01 | -.01 | .39** | | | | | | |
| | | | | [-.21, .23] | [-.23, .21] | [.19, .56] | | | | | | |
| 5. PRMQ | 80 | 24.31 | 6.94 | -.31** | .08 | -.26* | -.07 | | | | | |
| | | | | [-.49, -.09] | [-.14, .30] | [-.45, -.04] | [-.28, .16] | | | | | |
| 6. Cognitive Confidence | 80 | 11.54 | 4.02 | -.15 | .23* | -.17 | .03 | .65** | | | | |
| | | | | [-.36, .07] | [.01, .43] | [-.37, .05] | [-.19, .25] | [.50, .76] | | | | |
| 7. Performance Prediction | 80 | 71.30 | 17.36 | .17 | -.33** | -.02 | -.13 | -.12 | -.10 | | | |
| | | | | [-.05, .37] | [-.51, -.12] | [-.24, .20] | [-.34, .10] | [-.33, .10] | [-.31, .12] | | | |
| 8. PHQ-9 | 80 | 8.14 | 7.04 | -.21 | -.10 | -.07 | -.09 | .65** | .48** | .01 | | |
| | | | | [-.41, .01] | [-.23, .21] | [-.29, .15] | [-.30, .13] | [.51, .76] | [.29, .63] | [-.21, .23] | | |
| 9. CES-D | 80 | 26.40 | 2.75 | -.26* | .14 | -.07 | -.05 | .68** | .56** | -.09 | .81** | |
| | | | | [-.46, -.04] | [-.09, .35] | [-.28, .16] | [-.27, .17] | [.54, .78] | [.38, .69] | [-.31, .13] | [.71, .87] | |
| 10. Age | 80 | 19.45 | 2.75 | -.02 | .06 | -.17 | -.03 | -.07 | -.09 | -.15 | -.12 | -.10 |
| | | | | [-.24, .20] | [-.17, .27] | [-.37, .05] | [-.25, .19] | [-.28, .15] | [-.30, .13] | [-.36, .07] | [-.33, .10] | [-.31, .12] |
| 11. Gender[1] | 72 | - | - | -.11 | -.12 | .11 | .06 | .17 | .20 | -.20 | .07 | .12 |
| | | | | [-.33, .12] | [-.34, .11] | [-.12, .33] | [-.18, .29] | [-.06, .39] | [-.04, .41] | [-.42, .03] | [-.17, .29] | [-.11, .34] |
| 12. Gender[2] | 64 | - | - | .13 | .05 | -.08 | .07 | .27* | .03 | .10 | .28* | .24 |
| | | | | [-.12, .36] | [-.20, .29] | [-.32, .17] | [-.18, .31] | [.03, .48] | [-.22, .27] | [-.15, .34] | [.03, .49] | [-.01, .45] |
| 13. Gender[3] | 24 | - | - | .05 | -.08 | .00 | .16 | .47* | .29 | -.12 | .45* | .43* |
| | | | | [-.35, .44] | [-.47, .33] | [-.39, .41] | [-.26, .53] | [.09, .74] | [-.13, .62] | [-.50, .30] | [.06, .72] | [.03, .71] |

*Note*. *M* and *SD* are used to represent mean and standard deviation, respectively. Point-biserial correlation coefficients were calculated to assess the relationships between the binary categorical variable (gender) and the continuous variables. Pearson's correlation coefficients were calculated to evaluate the correlations between the continuous variables. Values in square brackets indicate the 95% confidence interval for each correlation. The confidence interval is a plausible range of population correlations that could have caused the sample correlation (Cumming, 2014). * indicates $p < .05$. ** indicates $p < .01$. Gender$^1$: Man = 0, Woman = 1. Gender$^2$: Women = 0, Transgender + nonbinary = 1. Gender$^3$: Men = 0, Transgender + nonbinary = 1.

A)




B)

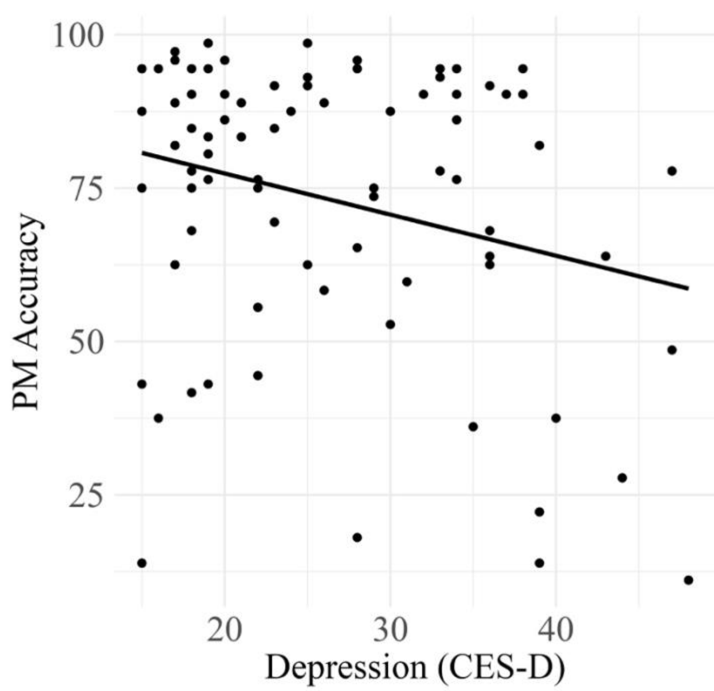
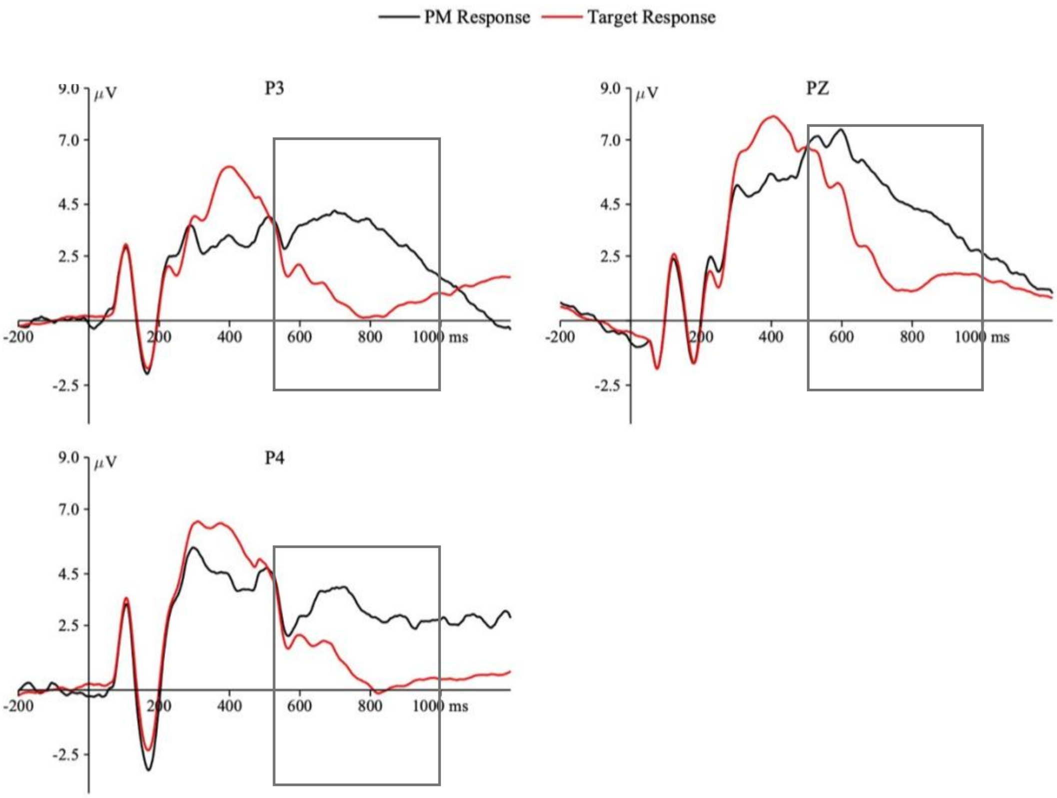
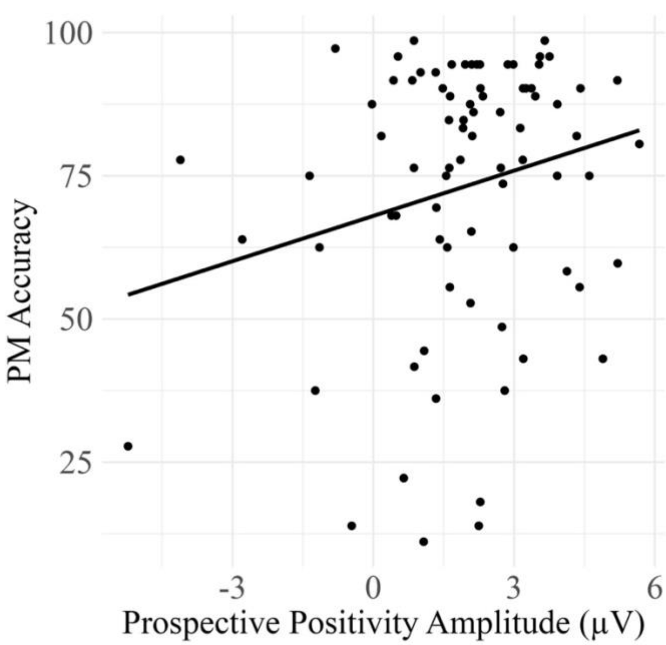



*Figure 3.* Results of Depression Levels Related to PM Accuracy. A) A scatterplot showing an increase in clinically relevant depression symptoms, measured by upper and lower quartile scores from the PHQ-9, is associated with lower PM accuracy. B) Another scatterplot showing an increase in reports of depressive symptoms, measured by the CES-D, is associated with lower PM accuracy.

A)


PM Response
Target Response
P3
PZ
P4
9.0
7.0
4.5
2.5
-2.5
μV
-200
200
400
600
800
1000 ms

B)


PM Accuracy
100
75
50
25
-3
0
3
6
Prospective Positivity Amplitude (μV)

C)

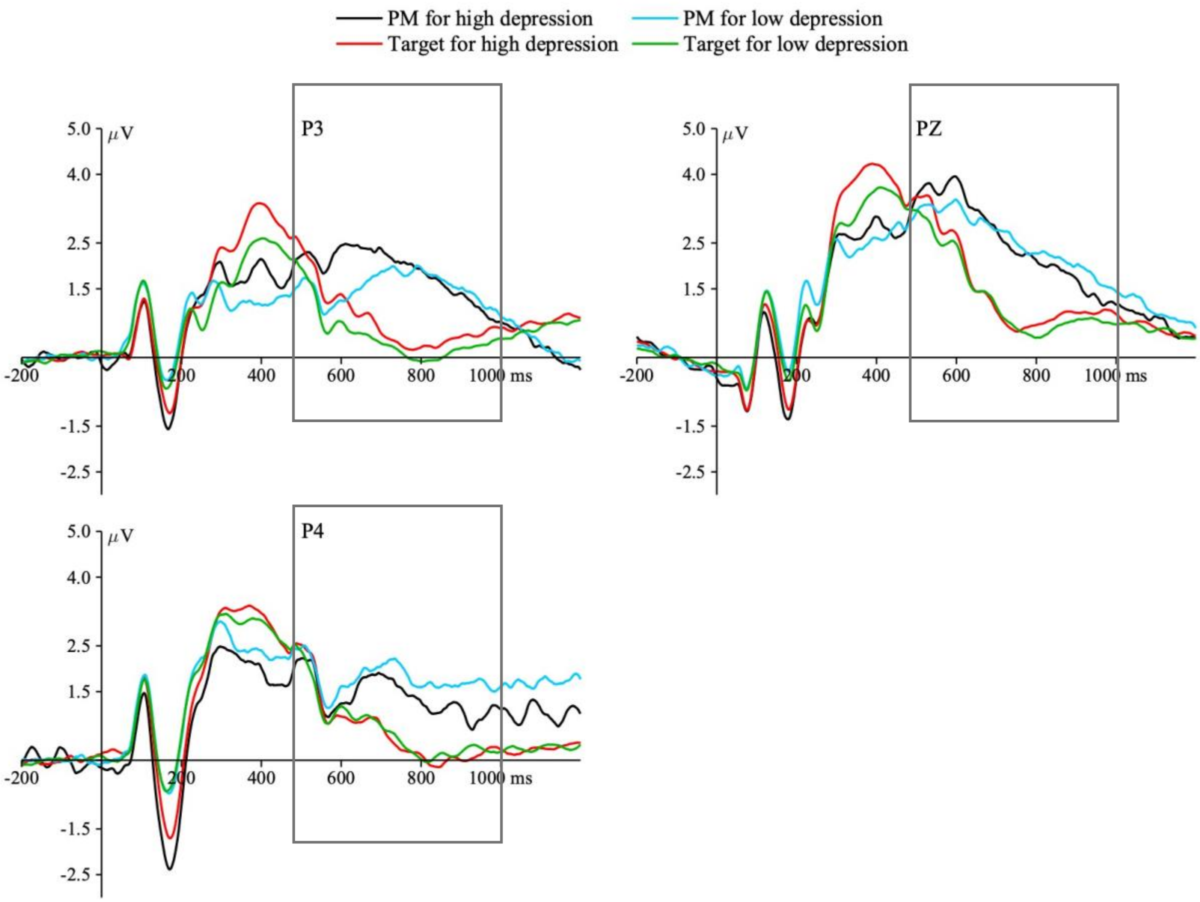
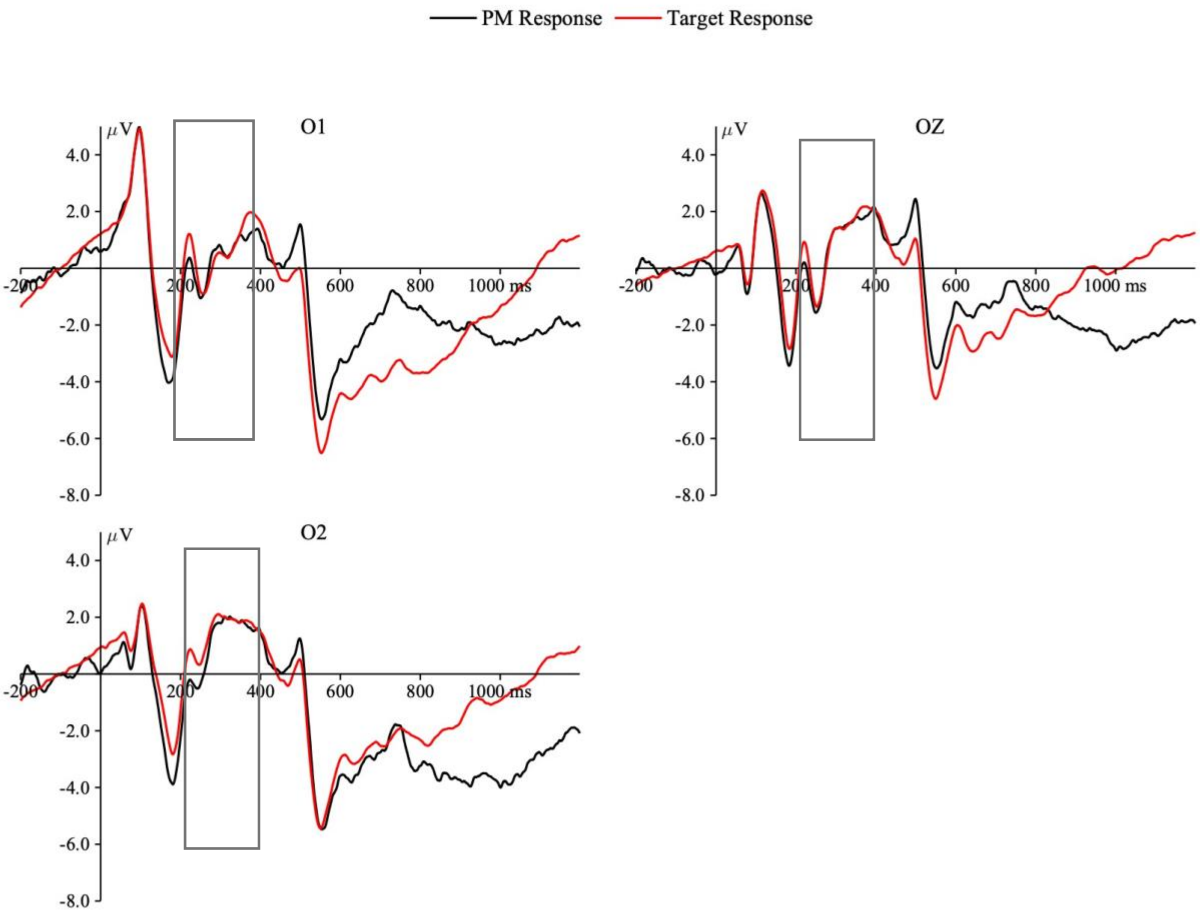



*Figure 4.* Results for Prospective Positivity Amplitude Related to Accuracy. A) ERP results for the prospective positivity at electrodes P3, Pz, and P4. The prospective positivity is characterized by a sustained positive peak 500 – 1000 ms after stimulus onset. B) A scatterplot showing an increase in prospective positivity amplitude was associated with an increase in PM accuracy. This increased amplitude suggests a potential heightened response of the intention retrieval component for participants with better PM performance. C) The neural responses during the PM trials for participants with high depression levels were not different in comparison to the participants with low depression levels. The ERP graph is a useful visualization tool, but it is not intended to reflect group-based analyses for the relationship between depression and intention retrieval.

A)



PM Response
Target Response
O1
OZ
O2
μV
4.0
2.0
-2.0
-4.0
-6.0
-8.0
-200
200
400
600
800
1000 ms

B)

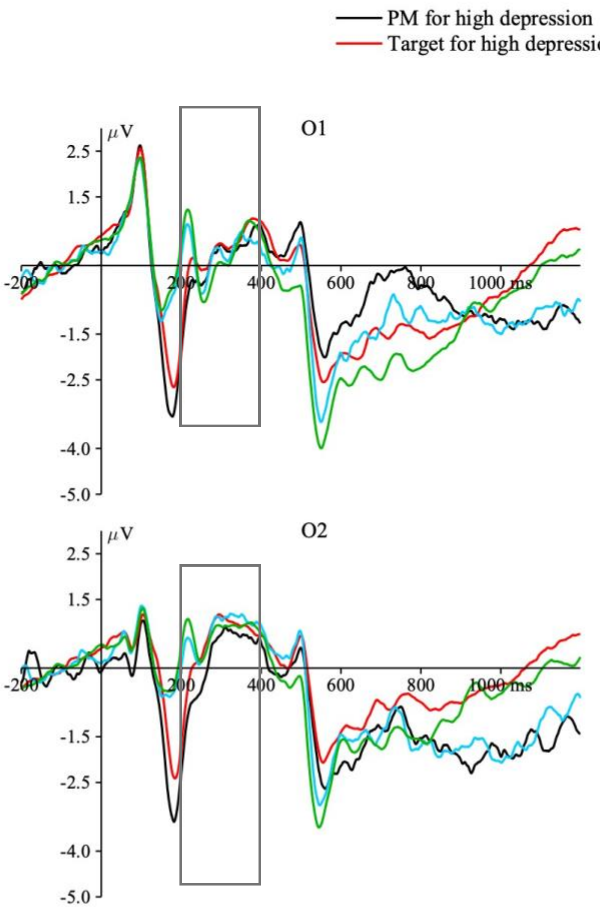



*Figure 5.* Results for N300 Amplitude Related to Accuracy. A) ERP results for the N300 at electrodes O1, Oz, and O2. The N300 is characterized by a brief negative peak, 200-400 ms after stimulus onset. There were no significant associations between N300 responses and PM performance. B) The neural responses during the PM trials for participants with high depression levels were not different in comparison to the participants with low depression levels. The ERP graph is a useful visualization tool, but it is not intended to reflect group-based analyses for the relationship between depression and cue detection.

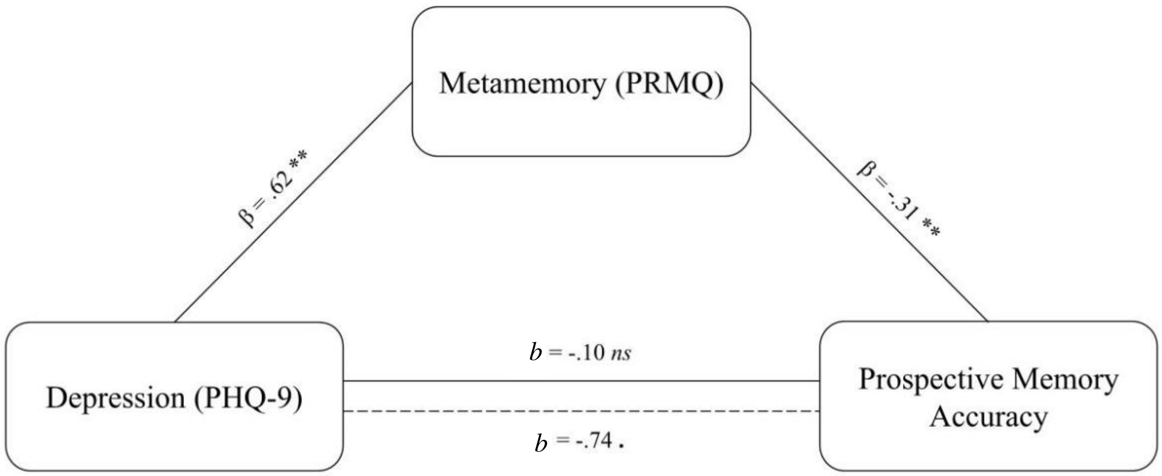



*Figure 6.* Model Results for Depression (PHQ-9) Relating to Prospective Memory Accuracy via Metamemory (PRMQ). Mediation: Depression from the PHQ-9 was indirectly associated with prospective memory accuracy via metamemory from the PRMQ. The solid line between depression and prospective memory accuracy represents the total effect (*c* path), while the dotted line represents the direct effect after accounting for the indirect effect (*c′* path). The indirect effect was significant, $ab = -.63$, $p = .017$. Analyses controlled for age and gender. $^{**}p<.01$, $^{*}p < .05$, . $p<.10$.

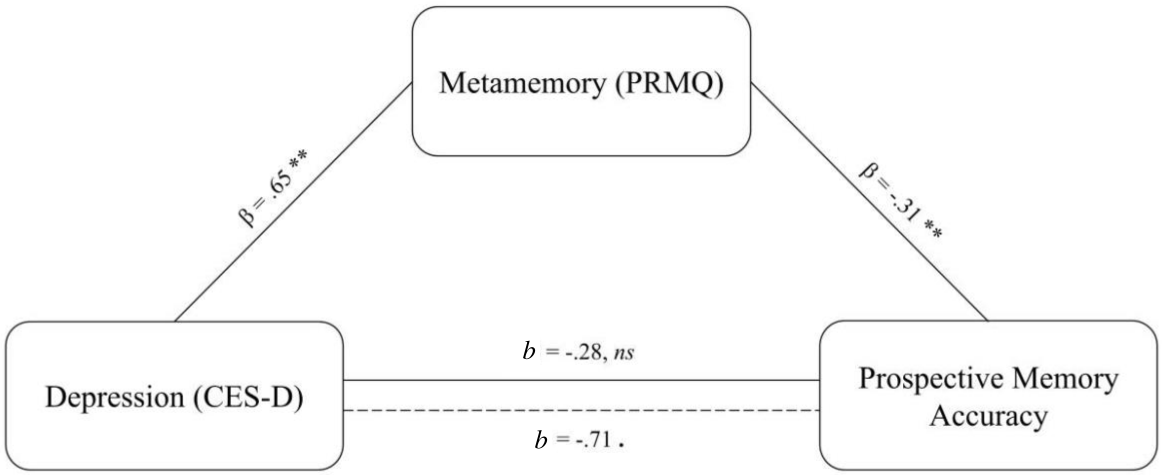



*Figure 7.* Model Results for Depression (CES-D) Relating to Prospective Memory Accuracy via Metamemory (PRMQ). Mediation: Depression from the CES-D was indirectly associated with prospective memory accuracy via metamemory from the PRMQ. The solid line between depression and prospective memory accuracy represents the total effect (*c* path), while the dotted line represents the direct effect after accounting for the indirect effect (*c′* path). The indirect effect was marginally significant, $ab = -.43$, $p = .065$. Analyses controlled for age and gender. **$p<.01$, *$p < .05$, . $p<.10$.

**TABLE 3**

Model Results for PHQ-9 Relating to PM Accuracy via PM-related Metamemory Beliefs (PRMQ) while controlling for age and gender

| Effect | Estimate | SE | CI Lower | CI Upper | *p*-value |
|---|---|---|---|---|---|
| Indirect | -0.63 | 0.27 | -1.17 | -0.11 | 0.02 |
| Direct | -0.10 | 0.43 | -0.95 | 0.75 | 0.80 |
| Total | -0.74 | 0.42 | -1.48 | 0.13 | 0.10 |

*Note*. Estimate refers to unstandardized betas, standard errors, confidence intervals, and *p*-values for the indirect, direct, and total effects.

**TABLE 4**
Model Results for CES-D Relating to PM Accuracy via PM-related Metamemory Beliefs (PRMQ) while controlling for age and gender

| Effect | Estimate | SE | CI Lower | CI Upper | *p*-value |
|---|---|---|---|---|---|
| Indirect | -0.43 | 0.22 | -0.86 | 0.03 | 0.07 |
| Direct | -0.27 | 0.42 | -1.12 | 0.53 | 0.50 |
| Total | -0.71 | 0.36 | -1.36 | 0.04 | 0.06 |

*Note*. Estimate refers to unstandardized betas, standard errors, confidence intervals, and *p*-values for the indirect, direct, and total effects.

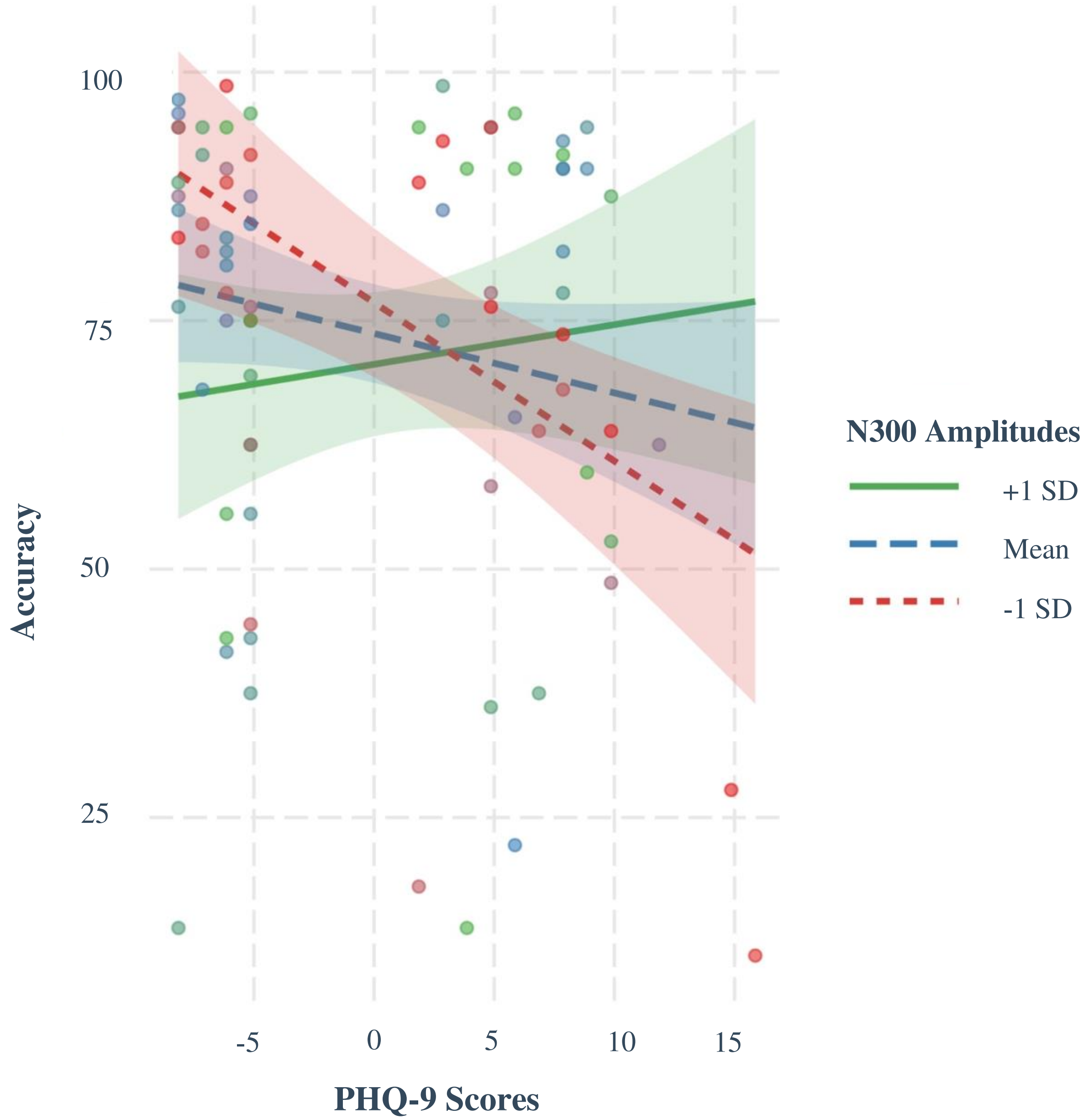



*Figure 8.* Results of Depression Levels Related to PM Accuracy Moderated by N300 Amplitudes. A scatterplot showing that in participants with larger (i.e., -1 SD, more negative amplitudes) N300 responses, increased depression levels, measured by upper and lower quartile scores from the PHQ-9, predict worse PM accuracy. The shaded areas represent 95% confidence intervals.

**TABLE 5**
Model Results for N300 Responses Moderating PHQ-9 and PM Accuracy while controlling for age and gender

| Effect | Std. $\beta$ | *p*-value |
|---|---|---|
| N300 | 0.01 | 0.91 |
| PHQ-9 | -0.22 | 0.05 |
| PHQ-9:N300 | 0.26 | 0.01 |

*Note*. Std. $\beta$ refers to standardized betas and *p*-values for the linear regression models and interaction model.

**TABLE 6**
Strength of Depression (PHQ-9) in Predicting Accuracy Across Levels of N300 while controlling for age and gender

| Effect | *b* | *p*-value |
|---|---|---|
| -1 SD | -1.59 | 0.00 |
| Average | -0.60 | 0.11 |
| +1 SD | 0.40 | 0.48 |

*Note*. *b* refers to unstandardized betas, *p*-values for -1 standard deviation (-1 SD), average, and +1 standard deviation (+1 SD).

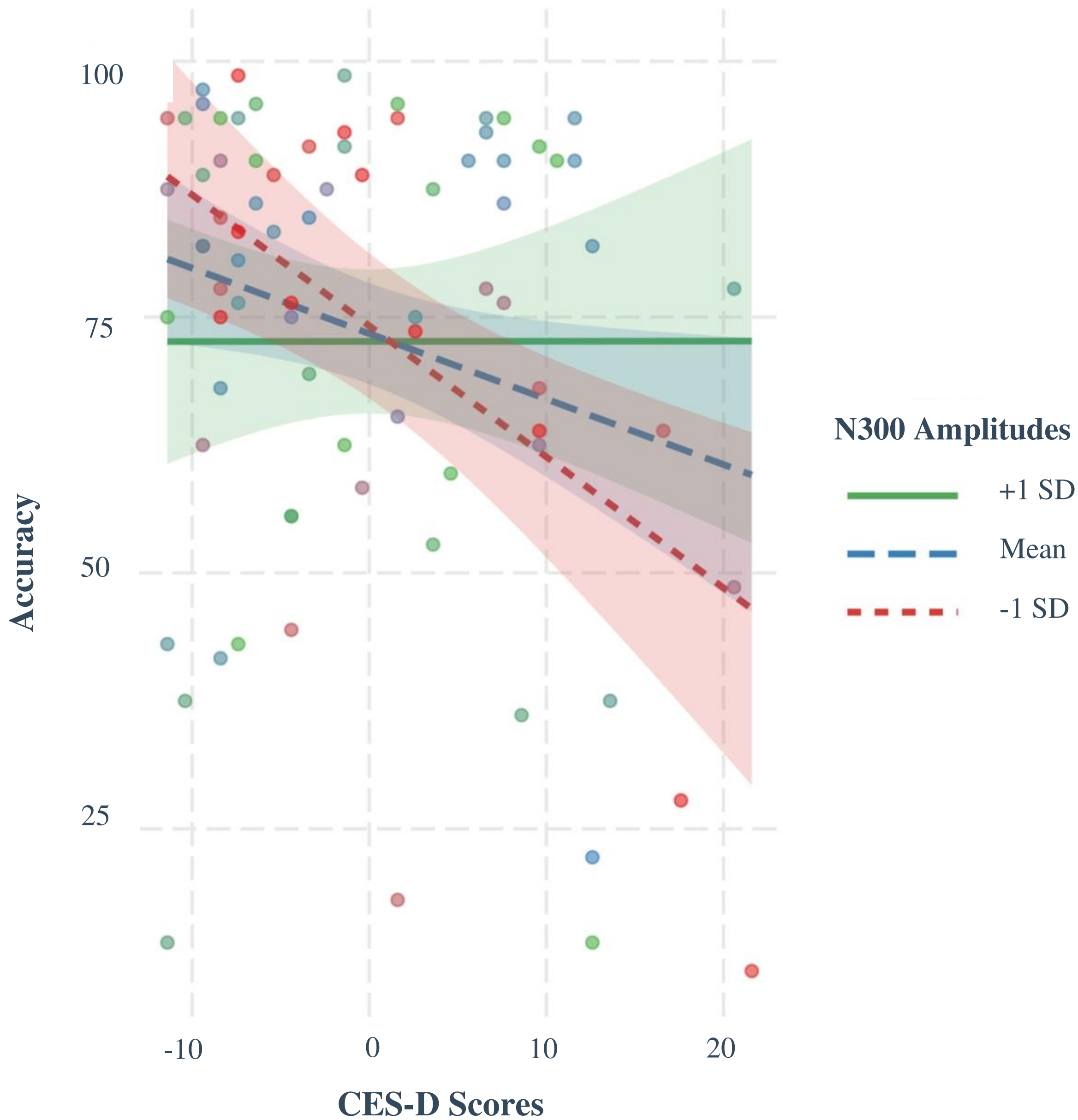



*Figure* 9. Results of Depression Levels Related to PM Accuracy Moderated by N300 Amplitudes. A scatterplot showing that in participants with mean and larger (i.e., -1 SD, more negative amplitudes) N300 responses, increased depression, levels measured by the CES-D, predict worse PM accuracy. The shaded areas represent 95% confidence intervals.

**TABLE 7**

Model Results for N300 Responses Moderating CES-D and PM Accuracy while controlling for age and gender

| Effect | Std. $\beta$ | $p$-value |
|---|---|---|
| N300 | 0.01 | 0.91 |
| CES-D | -0.28 | 0.02 |
| CES-D:N300 | 0.16 | 0.03 |

*Note*. Std. $\beta$ refers to standardized betas and $p$-values for the linear regression models and interaction model.

**TABLE 8**
Strength of Depression (CES-D) in Predicting Accuracy Across Levels of N300 while controlling for age and gender

| Effect | *b* | *p*-value |
|---|---|---|
| -1 SD | -1.28 | 0.00 |
| Average | -0.64 | 0.03 |
| +1 SD | 0.00 | 1.00 |

*Note*. *b* refers to unstandardized betas, *p*-values for -1 standard deviation (-1 SD), average, and +1 standard deviation (+1 SD).

**TABLE 9**
Model Results for PHQ-9 Relating to PM Accuracy via PM-related Metamemory Beliefs (PRMQ) with Cue Detection as a Moderator while controlling for age and gender

| Effect | Estimate | SE | CI Lower | CI Upper | *p*-value |
|---|---|---|---|---|---|
| Indirect | -0.51 | 0.26 | -1.03 | 0.02 | 0.06 |
| Direct | -0.11 | 0.41 | -0.92 | 0.68 | 0.80 |
| Total | -0.62 | 0.39 | -1.33 | 0.19 | 0.14 |

*Note*. Estimate refers to unstandardized betas, standard errors, confidence intervals, and *p*-values for the indirect, direct, and total effects.

**TABLE 10**

Model Results for CES-D Relating to PM Accuracy via PM-related Metamemory Beliefs (PRMQ) with Cue Detection as a Moderator while controlling for age and gender

| Effect | Estimate | SE | CI Lower | CI Upper | *p*-value |
|---|---|---|---|---|---|
| Indirect | -0.36 | 0.22 | -0.77 | 0.12 | 0.14 |
| Direct | -0.29 | 0.41 | -1.08 | 0.52 | 0.52 |
| Total | -0.65 | 0.35 | -1.27 | 0.11 | 0.0 |

*Note*. Estimate refers to unstandardized betas, standard errors, confidence intervals, and *p*-values for the indirect, direct, and total effects.

**TABLE 11**
Main Effects of Regression Models for PHQ-9 controlling for age and gender

| Effect | Std. $\beta$ | $p$-value |
|---|---|---|
| PHQ-9 on Accuracy | -0.22 | 0.05 |
| PHQ-9 on PRMQ | 0.62 | < 0.001 |
| PRMQ on Accuracy | -0.33 | 0.01 |

Main Effects of Regression Models for PHQ-9 controlling for only gender

| Effect | Std. $\beta$ | $p$-value |
|---|---|---|
| PHQ-9 on Accuracy | -0.22 | 0.06 |
| PHQ-9 on PRMQ | 0.62 | < 0.001 |
| PRMQ on Accuracy | -0.33 | 0.01 |

*Note*. Std. $\beta$ refers to standardized betas and $p$-values of regression models.

**TABLE 12**
Main Effects of Regression Models for CES-D controlling for age and gender

| Effect | Std. $\beta$ | *p*-value |
|---|---|---|
| CES-D on Accuracy | -0.28 | 0.02 |
| CES-D on PRMQ | 0.65 | < 0.001 |
| PRMQ on Accuracy | -0.33 | 0.01 |

Main Effects of Regression Models for CES-D controlling for only gender

| Effect | Std. $\beta$ | *p*-value |
|---|---|---|
| CES-D on Accuracy | -0.27 | 0.02 |
| CES-D on PRMQ | 0.65 | < 0.001 |
| PRMQ on Accuracy | -0.33 | 0.01 |

*Note*. Std. $\beta$ refers to standardized betas and *p*-values of regression models.

**TABLE 13**

Model Results for PHQ-9 Relating to PM Accuracy via PM-related Metamemory Beliefs (PRMQ) while controlling for only gender

| Effect | Estimate | SE | CI Lower | CI Upper | *p*-value |
|---|---|---|---|---|---|
| Indirect | -0.63 | 0.27 | -1.18 | -0.14 | 0.01 |
| Direct | -0.09 | 0.43 | -0.90 | 0.76 | 0.86 |
| Total | -0.73 | 0.41 | -1.46 | 0.14 | 0.10 |

*Note*. Estimate refers to unstandardized betas, standard errors, confidence intervals, and *p*-values for the indirect, direct, and total effects.

**TABLE 14**

Model Results for CES-D Relating to PM Accuracy via PM-related Metamemory Beliefs (PRMQ) while controlling for only gender

| Effect | Estimate | SE | CI Lower | CI Upper | *p*-value |
|---|---|---|---|---|---|
| Indirect | -0.43 | 0.22 | -0.89 | 0.01 | 0.05 |
| Direct | -0.27 | 0.41 | -1.08 | 0.56 | 0.52 |
| Total | -0.70 | 0.35 | -1.36 | 0.04 | 0.06 |

*Note*. Estimate refers to unstandardized betas, standard errors, confidence intervals, and *p*-values for the indirect, direct, and total effects.

**TABLE 15**
Model Results for N300 Responses Moderating PHQ-9 and PM Accuracy while controlling for only gender

| Effect | Std. *β* | *p*-value |
|---:|---:|---:|
| N300 | 0.01 | 0.90 |
| PHQ-9 | -0.22 | 0.06 |
| PHQ-9:N300 | 0.26 | 0.01 |

*Note*. Std. *β* refers to standardized betas and *p*-values for the linear regression models and interaction model.

**TABLE 16**
Strength of Depression (PHQ-9) in Predicting Accuracy Across Levels of N300 while controlling for only gender

| Effect | *b* | *p*-value |
|---|---|---|
| -1 SD | -1.59 | 0.00 |
| Average | -0.59 | 0.11 |
| +1 SD | 0.41 | 0.46 |

*Note*. *b* refers to unstandardized betas, *p*-values for -1 standard deviation (-1 SD), average, and +1 standard deviation (+1 SD).

**TABLE 17**

Model Results for N300 Responses Moderating CES-D and PM Accuracy while controlling for only gender

| Effect | Std. $\beta$ | $p$-value |
|---|---|---|
| N300 | 0.01 | 0.90 |
| CES-D | -0.27 | 0.02 |
| CES-D:N300 | 0.17 | 0.03 |

*Note*. Std. $\beta$ refers to standardized betas and $p$-values for the linear regression models and interaction model.

**TABLE 18**

Strength of Depression (CES-D) in Predicting Accuracy Across Levels of N300 while controlling for only gender

| Effect | *b* | *p*-value |
|---|---|---|
| -1 SD | -1.28 | 0.00 |
| Average | -0.64 | 0.03 |
| +1 SD | 0.00 | 0.99 |

*Note*. *b* refers to unstandardized betas, *p*-values for -1 standard deviation (-1 SD), average, and +1 standard deviation (+1 SD).

**TABLE 19**

Model Results for PHQ-9 Relating to PM Accuracy via PM-related Metamemory Beliefs (PRMQ) with Cue Detection as a Moderator while controlling for only gender

| Effect | Estimate | SE | CI Lower | CI Upper | *p*-value |
|---|---|---|---|---|---|
| Indirect | -0.51 | 0.26 | -1.03 | 0.02 | 0.06 |
| Direct | -0.10 | 0.41 | -0.92 | 0.71 | 0.84 |
| Total | -0.61 | 0.39 | -1.31 | 0.21 | 0.15 |

*Note*. Estimate refers to unstandardized betas, standard errors, confidence intervals, and *p*-values for the indirect, direct, and total effects.

**TABLE 20**

Model Results for CES-D Relating to PM Accuracy via PM-related Metamemory Beliefs (PRMQ) with Cue Detection as a Moderator while controlling for only gender

| Effect | Estimate | SE | CI Lower | CI Upper | *p*-value |
|---|---|---|---|---|---|
| Indirect | -0.36 | 0.22 | -0.79 | 0.11 | 0.12 |
| Direct | -0.29 | 0.41 | -1.06 | 0.54 | 0.55 |
| Total | -0.65 | 0.35 | -1.28 | 0.09 | 0.09 |

*Note*. Estimate refers to unstandardized betas, standard errors, confidence intervals, and *p*-values for the indirect, direct, and total effects.

**TABLE 21**
Model Results for Conditional Indirect Effects of PHQ-9 Relating to PM Accuracy via PM-related Metamemory Beliefs (PRMQ) Across Levels of the N300 on the Direct Path while controlling for only gender

Model Results: PHQ-9 Model at -1 SD N300

| Effect | Estimate | SE | CI Lower | CI Upper | *p*-value |
|---|---|---|---|---|---|
| Indirect | -0.63 | 0.27 | -1.18 | -0.13 | 0.01 |
| Direct | -0.09 | 0.44 | -0.93 | 0.79 | 0.86 |
| Total | -0.73 | 0.42 | -1.48 | 0.15 | 0.11 |

Model Results: PHQ-9 Model at Average N300

| Effect | Estimate | SE | CI Lower | CI Upper | *p*-value |
|---|---|---|---|---|---|
| Indirect | -0.63 | 0.27 | -1.19 | -0.13 | 0.01 |
| Direct | -0.09 | 0.43 | -0.92 | 0.75 | 0.84 |
| Total | -0.73 | 0.41 | -1.50 | 0.13 | 0.09 |

Model Results: PHQ-9 Model at +1 SD N300

| Effect | Estimate | SE | CI Lower | CI Upper | *p*-value |
|---|---|---|---|---|---|
| Indirect | -0.63 | 0.26 | -1.18 | -0.13 | 0.01 |
| Direct | -0.09 | 0.43 | -0.91 | 0.75 | 0.86 |
| Total | -0.73 | 0.41 | -1.47 | 0.14 | 0.10 |

*Note*. Estimate refers to unstandardized betas, standard errors, confidence intervals, and *p*-values for the indirect, direct, and total effects.

**TABLE 22**
Model Results for Conditional Indirect Effects of CES-D Relating to PM Accuracy via PM-related Metamemory Beliefs (PRMQ) Across Levels of the N300 on the Direct Path while controlling for only gender

Model Results: CES-D Model at -1 SD N300

| Effect | Estimate | SE | CI Lower | CI Upper | *p*-value |
|---|---|---|---|---|---|
| Indirect | -0.43 | 0.22 | -0.88 | -0.0001 | 0.05 |
| Direct | -0.27 | 0.42 | -1.07 | 0.59 | 0.52 |
| Total | -0.70 | 0.35 | -1.36 | 0.05 | 0.07 |

Model Results: CES-D Model at Average N300

| Effect | Estimate | SE | CI Lower | CI Upper | *p*-value |
|---|---|---|---|---|---|
| Indirect | -0.43 | 0.22 | -0.88 | 0.004 | 0.05 |
| Direct | -0.27 | 0.41 | -1.08 | 0.55 | 0.52 |
| Total | -0.70 | 0.35 | -1.33 | 0.03 | 0.06 |

Model Results: CES-D Model at +1 SD N300

| Effect | Estimate | SE | CI Lower | CI Upper | *p*-value |
|---|---|---|---|---|---|
| Indirect | -0.43 | 0.22 | -0.88 | -0.01 | 0.05 |
| Direct | -0.27 | 0.42 | -1.07 | 0.56 | 0.53 |
| Total | -0.70 | 0.36 | -1.35 | 0.04 | 0.06 |

*Note*. Estimate refers to unstandardized betas, standard errors, confidence intervals, and *p*-values for the indirect, direct, and total effects.

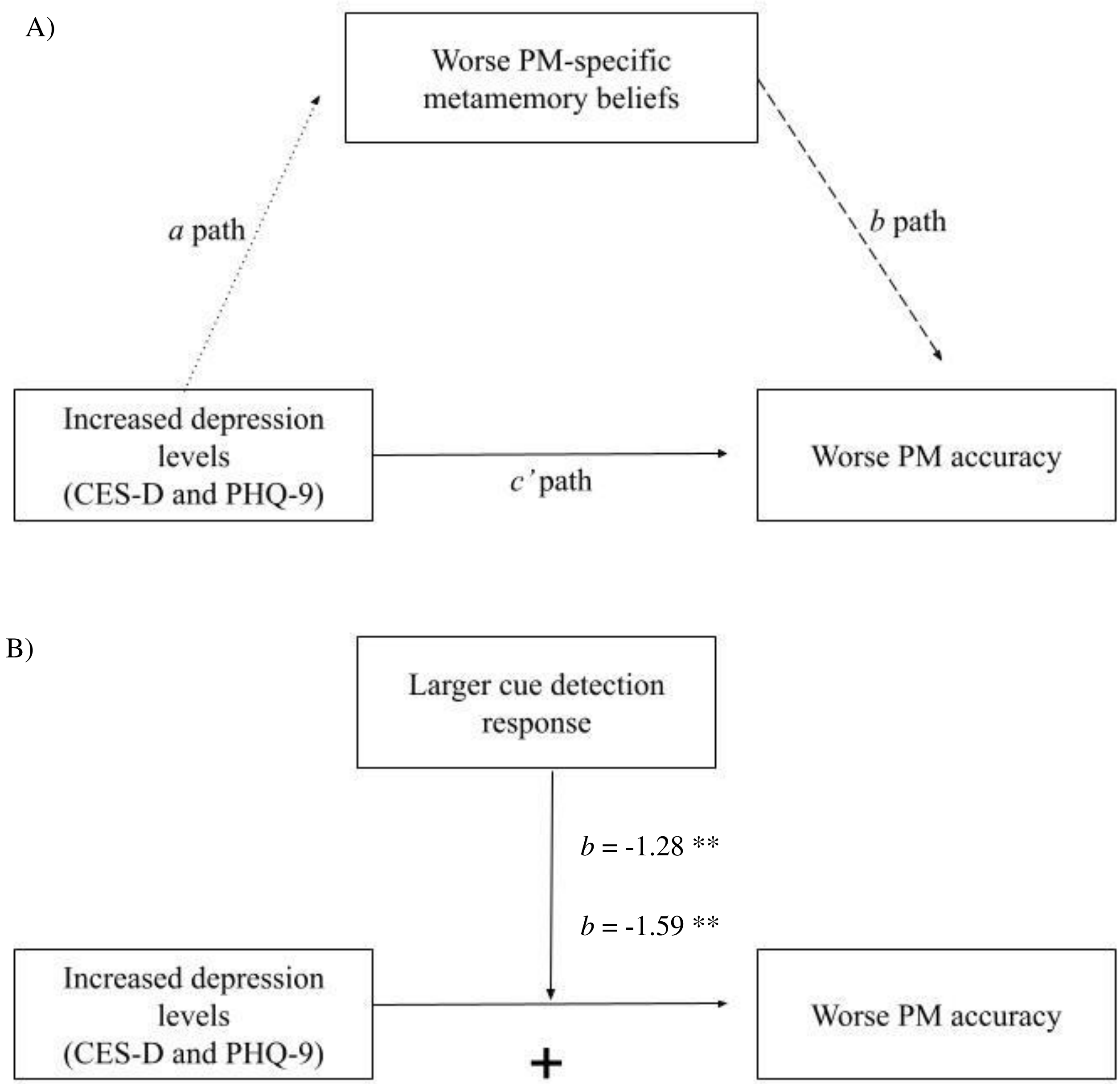



*Figure 10.* Model Relating Depression to PM Performance via Metamemory Independent from Cue Detection's Moderating Effect. A) The relationship between depression (CES-D and PHQ-9) and accuracy is mediated by poor PM-specific metamemory beliefs. B) Independently, the role of depression in predicting impaired PM performance is strengthened when students demonstrate larger cue detection responses (PHQ-9: $\beta = .26$, $p = .009$, at -1 SD $b = -1.59$, $p < .01$; CES-D: $\beta = .16$, $p = .028$, at -1 SD $b = -1.28$, $p = .00$). The indirect effect of the mediation remains significant or marginally significant across every level of cue detection responses. . indicates $p < .10$. * indicates $p < .05$. ** indicates $p < .01$

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# CHAPTER 5: FINAL CONCLUSION AND SIGNIFICANCE

## 5.1. CONCLUSIONS

This dissertation is comprised of three papers that build upon each other to provide novel insights on the complex interplay between metamemory beliefs, depression, and PM performance. The implementation of neurophysiology, PM-specific metamemory beliefs, and a broad spectrum of depression levels expands the current field, as no study has used this methodology to examine the combination of these factors simultaneously. While the results for the final model differ from the initially proposed model, these findings align with previous literature suggesting attention-related differences and low self-worth have important implications for individuals experiencing depression, further demonstrating valuable nuances not yet seen in past studies. Through these three studies, researchers and college students can have a better understanding of the mechanisms that both harm and support future-oriented goal directed abilities.

In Study 1, linear regression results revealed that better PM-specific metamemory beliefs from the PRMQ predicted better PM accuracy, while higher levels of cognitive confidence and higher performance predictions predicted faster reaction times. Further, more positive PM-specific metamemory evaluations predicted larger intention retrieval responses, measured by prospective positivity amplitudes. These results suggested that more positive beliefs in one's abilities supports the neurocognitive component involved in maintaining the intended goal in mind, as well as behavioral PM abilities. This work expands previous research indicating that metacognition and metamemory are important for guiding one's cognitive resources (Fiedler et al., 2019; Nelson, 1990). Students with more positive metamemory beliefs may have better control on how they allocate cognitive resources and focus on task demands. In contrast, college students who experience more negative metamemory beliefs may struggle with managing cognitive effort. Specifically for PM, students with strong confidence in their abilities may be more adept at identifying the relevant goal-oriented heuristic cues necessary for successful task performance, which is shown to be a key factor in the positive relationship between metacognition and performance outcomes (Hoch et al., 2023; Rhodes, 2019).

Study 2 demonstrated that higher depression levels predicted more negative beliefs in PM-related skills and cognitive abilities. More importantly, the relationship between depression and PM-related metamemory beliefs, measured by the PRMQ and performance predictions for the task, interacted when predicting cue detection responses, measured via N300 amplitudes. While there was no main effect of depression on the neurocognitive components, the interaction effect revealed metamemory beliefs as a moderator. More specifically, for college students with negative metamemory beliefs, high depression levels predicted a larger cue detection response. This moderation was only seen for the PHQ-9, suggesting that this effect existed more prominently for students with potentially diagnosable levels of depression, as the PHQ-9 is validated as a diagnostic tool for major depressive disorder (Levis et al., 2019).

These findings suggested that college students with depression may have altered their attention towards monitoring the environment for the cue, as opposed to maintaining their intended goal in mind. These results align with previous work demonstrating variation in attention-related resources and effort for adults with depression (Fuseda et al., 2022; Keller et al., 2019; Rummel & Meiser, 2013), and they expand on past research by demonstrating that more negative metamemory beliefs may worsen this relationship. Students can use this information to better understand how depression and metamemory beliefs may change their cognitive effort, which they can adjust if they wish to have a more even allocation of cognitive resources.

Finally, Study 3 revealed both a broad spectrum of depression symptoms (i.e., CES-D) and clinically relevant depression levels (i.e., PHQ-9) predicted impaired PM accuracy, but not reaction time. Only larger intention retrieval responses predicted better PM accuracy, while cue detection was not related to accuracy or reaction time. Exploratory analyses demonstrated that PM-specific metamemory beliefs fully mediated the relationship between depression levels and PM performance. Further, a moderation effect of cue detection responses on the role of depression in PM performance was also observed. More specifically, larger cue detection responses strengthened the negative role of depression on PM accuracy. When examining the moderated mediation results, the conditional indirect mediation effects remained robust across low, average, and high levels of cue detection responses, suggesting that regardless of monitoring behaviors, metamemory beliefs played an important role in understanding how depression impairs PM performance. These results align with previous work suggesting that cue detection may be implicated in depression-specific PM impairments, and depression may be related to a misallocation of cognitive resources and ineffective coping when performing goal-directed tasks (Chen et al., 2013; Fuseda et al., 2022; Keller et al., 2019; Li et al., 2014). Study 3 expands on this literature by demonstrating how depression-related attentional biases towards monitoring the environment for goal-related cues can worsen depression's negative role in PM performance.

Further, these results support previous studies suggesting that metamemory beliefs likely contribute to the relationship between depression and PM skills (Da Silva Coelho et al., 2023; Huber et al., 2022), and they expand upon this work by specifically revealing negative metamemory beliefs to be a mediator. These findings also align with the idea that concentration and feelings of worthlessness are key symptoms in defining depression (Chand & Arif, 2024), and they provide evidence that these symptoms may be the mechanism through which depression impairs PM performance. This mediation effect was found to be consistent across cue detection levels, indicating that while larger cue detection responses can further impair depression-specific PM deficits, reduced metamemory beliefs remain a relatively powerful and resilient mediator. See Figure 2 for the full conceptual model, also shown in Study 3. With these findings, college students experiencing depression have flexibility if they hope to support their goal-directed abilities. They could see strengthened PM skills by working to more evenly distribute their cognitive effort between monitoring the environment for cues and maintaining the intended goal in mind, and they could specifically focus on remediating their depressive symptoms of worthlessness and reduced belief in their abilities.

## 5.2. SIGNIFICANCE

As a whole, this dissertation contributes to a deeper understanding of the neurocognitive and psychological mechanisms that may underly PM performance. The current project integrates and expands upon multiple scientific fields, including metacognition, neurophysiology, cognitive effort, psychopathologies, goal-directed behaviors, and memory skills. Through this work, all college students, whether suffering depressive symptoms or not, can understand how their psychological and emotional experiences may be impairing their PM skills, seek to address these mechanisms, and support successful completion of their goals, enhancing their overall wellbeing. Finally, researchers can expand on this work by further assessing how manipulations and treatments of metamemory beliefs, attention allocation, and specific depressive symptoms may support PM performance. The findings of this dissertation have real-world implications for how college students can enhance their cognitive abilities to more effectively complete and submit their assignments, create and stick with study plans, and balance their personal and academic lives with greater ease and success.

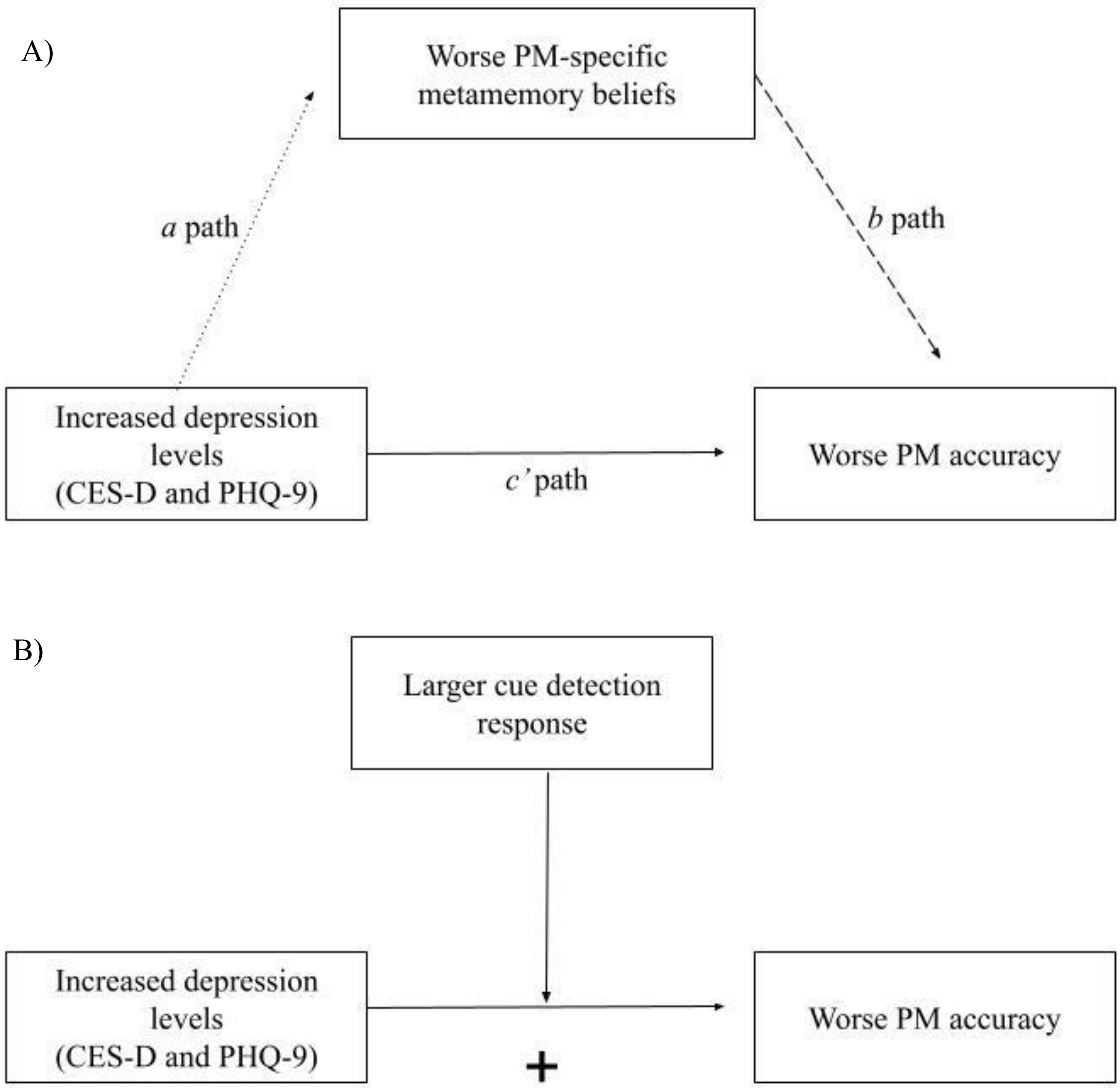


*Figure 2.* Model Relating Depression to PM Performance via Metamemory Independent from Cue Detection's Moderating Effect. A) The relationship between depression and metamemory beliefs (*a* path) was assessed in Study 2, represented by the dotted line. The relationship between metamemory beliefs and PM accuracy was assessed in Study 1 (*b* path), represented by the dashed line. The relationship between depression and PM accuracy (*c'* path) was assessed in Study 3, represented by the solid line. The mediation role of metamemory was assessed as exploratory analyses in Study 3. The relationship between depression (CES-D and PHQ-9) and accuracy is mediated by negative PM-specific metamemory beliefs. B) The moderation role of cue detection on the *c*' path was assessed as exploratory analyses in Study 3. Independently from the mediation, the role of depression in predicting impaired PM performance is strengthened when students demonstrate larger cue detection responses. The indirect effect of the mediation remains significant or marginally significant across every level of cue detection responses.

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APPENDIX A

**Prospective and Retrospective Memory Questionnaire:**

In order to understand why people make memory mistakes, we need to find out about the kinds of mistakes people make, and how often they are made in normal everyday life. We would like you to tell us how often these kind of things happen to you.

Please indicate by ticking the appropriate box. Please make sure you answer all of the questions even if they don't seem entirely applicable to your situation.

| Using the following scale: | Very Often | Quite Often | Sometimes | Rarely | Never |
|---|---|---|---|---|---|

1. Do you decide to do something in a few minutes' time and then forget to do it?
2. Do you fail to recognize a place you have visited before?
3. Do you fail to do something you were supposed to do a few minutes later even though it's there in front of you, like take a pill or turn off the kettle?
4. Do you forget something that you were told a few minutes before?
5. Do you forget appointments if you are not prompted by someone else or by a reminder such as a calendar or diary?
6. Do you fail to recognize a character in a radio or television show from scene to scene?
7. Do you forget to buy something you planned to buy, like a birthday card, even when you see the shop?
8. Do you fail to recall things that have happened to you in the last few days?
9. Do you repeat the same story to the same person on different occasions?
10. Do you intend to take something with you, before leaving a room or going out, but minutes later leave it behind, even though it's there in front of you?
11. Do you mislay something that you have just put down, like a magazine or glasses?
12. Do you fail to mention or give something to a visitor that you were asked to pass on?
13. Do you look at something without realising you have seen it moments before?
14. If you tried to contact a friend or relative who was out, would you forget to try again later?
15. Do you forget what you watched on television the previous day?
16. Do you forget to tell someone something you had meant to mention a few minutes ago?

** Items 1, 3, 5, 7, 10, 12, 14, 16 comprise the PM subscale*

**Cognitive Confidence Subscale of the MCQ-30**:

Please read each item and indicate how much you generally agree with it. Please respond to all the items, there are no right or wrong answers.

1= Do not agree, 2= Agree slightly, 3 = Agree moderately, 4=Agree very much

1. I have little confidence in my memory for words and names.
2. My memory can mislead me at times.
3. I have a poor memory.
4. I have little confidence in my memory for places.
5. I do not trust my memory.
6. l have little confidence in my memory for actions.

**Performance prediction for PM task:**

After providing task instructions for the visual search prospective memory test, the researcher will ask, “On a scale of 0% - 100%, how likely are you to correctly perform the task?”

The participant will provide a verbal response.

0%: (‘‘surely will not recall’’) to 100%: (‘‘surely will recall’’)

**Patient Health Questionnaire-9**

Over the last two weeks, how often have you been bothered by any of the following problems?

| Not at all | Several days | More than half the days | Nearly every day |
|---|---|---|---|

1. Little interest or pleasure in doing things.
2. Feeling down, depressed, or hopeless.
3. Trouble falling or staying asleep, or sleeping too much.
4. Feeling tired or having little energy.
5. Poor appetite or overeating.
6. Feeling bad about yourself...or that you are a failure or have let yourself or your family down.
7. Trouble concentrating on things, such as reading the newspaper or watching television.
8. Moving or speaking so slowly that other people could have noticed. Or the opposite...being so fidgety or restless that you have been moving around a lot more than usual.
9. Thoughts that you would have been better off dead, or of hurting yourself.

**Center for Epidemiological Studies – Depression Scale:**

Below is a list of the ways you might have felt or behaved. Please tell me how often you have felt this way during the past week.

| Rarely or none of the time (less than 1 day ) | Some or a little of the time (1-2 days) | Occasionally or a moderate amount of time (3-4 days) | Most or all of the time (5-7 days) |
|---|---|---|---|

1. I was bothered by things that usually don't bother me.
2. I did not feel like eating; my appetite was poor.
3. I felt that I could not shake off the blues even with help from my family or friends.
4. I felt I was just as good as other people.
5. I had trouble keeping my mind on what I was doing.
6. I felt depressed.
7. I felt that everything I did was an effort.
8. I felt hopeful about the future.
9. I thought my life had been a failure.
10. I felt fearful.
11. My sleep was restless.
12. I was happy.
13. I talked less than usual.
14. I felt lonely.
15. People were unfriendly.
16. I enjoyed life.
17. I had crying spells.
18. I felt sad.
19. I felt that people dislike me.
20. I could not get "going."

** The scoring of positive items is reversed (4, 8, 12, 16)*

APPENDIX B

## Task Instructions

All participants should use the RIGHT hand.

**A. Search task (first set of instructions):**
In this task, you will first see a target letter in the center of the screen. This will be followed by a pair of letters. Your task is to determine if the target letter is one of the letters in the pair. If the target is present, press “v” with your left index finger. If the target is absent, press “b” with your right index finger. The letters will flash quickly, but you will have up to 5 seconds to make a choice. Please try to answer as quickly as you can.

First you will complete practice trials, followed by the real trials.

Do you have any questions?

You will perform this task for about 5 minutes, then a black screen that says “STOP, wait for researcher” will appear. When that screen comes up, I will come back to give you more instructions. Press the space bar to begin the practice trials.

**B. Prospective memory task (second set of instructions):**
In the next blocks of trials, you will perform the same search task as before and a prospective memory task. If the pair of letters contains a “D” or an “M”, press only the “n” key with your right middle finger. Otherwise, decide whether the target letter is present in the pair, same as you were doing before with the “v” and “b” keys.

It is the same task as before, now with an extra rule of pressing “n” when you see “D” or “M”. You will never have to press multiple keys for one trial.

The letters will flash quickly, but you will have up to 5 seconds to make a choice. Please try to answer as quickly as you can.

First you will complete practice trials, followed by the real trials. You will be given a couple of opportunities for breaks during the task

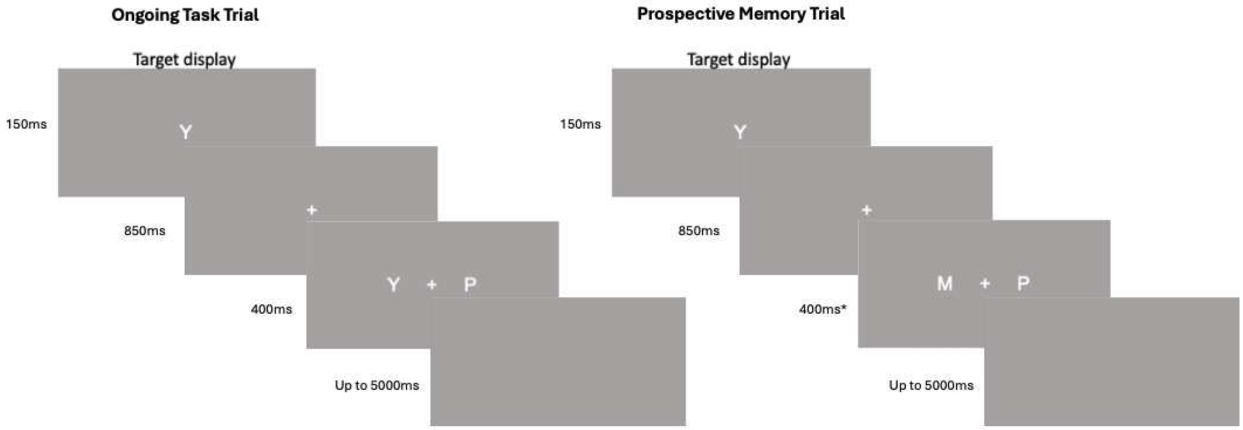
Do you have any questions about how to perform the task?

On a scale of 0% - 100%, how likely are you to correctly perform the task? **Be sure to write down their response on the Participant Information Sheet**

Press the space bar to begin the practice trials.

Ongoing Task & Prospective Memory Task Example:

Example images from task:



APPENDIX C

Excerpt of the code used to test linear regression:

```
## Regression: Depression predicting metamemory controlling for age and gender
```{r}
fit1 <- lm(scale(PRMQ1) ~ scale(PHQ9) + Gender1 + Age, data = PMD)
summary(fit1)

fit2 <- lm(scale(Confidence) ~ scale(PHQ9) + Gender1 + Age, data = PMD)
summary(fit2)

fit3 <- lm(scale(JOL) ~ scale(PHQ9) + Gender1 + Age, data = PMD)
summary(fit3)

fit4 <- lm(scale(PRMQ1) ~ scale(CESD) + Gender1 + Age, data = PMD)
summary(fit4)

fit5 <- lm(scale(Confidence) ~ scale(CESD) + Gender1 + Age, data = PMD)
summary(fit5)

fit6 <- lm(scale(JOL) ~ scale(CESD) + Gender1 + Age, data = PMD)
summary(fit6)
```
```

Excerpt of the code used to test interactions:

```
## ERP components (N300 and PP) moderating the relationship between depression and PM
accuracy
```{r}
lm1 <- lm(Accuracy ~ PHQ9_c * N300_c + Gender1 + Age, PMD)
summary(lm1)

lm2 <- lm(Accuracy ~ CESD_c * N300_c + Gender1 + Age, PMD)
summary(lm2)

lm3 <- lm(Accuracy ~ PHQ9_c * PP_c + Gender1 + Age, PMD)
summary(lm3)

lm4 <- lm(Accuracy ~ CESD_c * PP_c + Gender1 + Age, PMD)
summary(lm4)
```
```

````
## Simple slopes
### IV: PHQ9 * N300
```{r}
fitInt <- lm(Accuracy ~ PHQ9_c * N300_c + Gender1 + Age, data = PMD)
summary(fitInt)

sim_slopes(
  fitInt,
  PHQ9_c,
  N300_c,
  mod2 = NULL,
  modx.values = NULL,
  mod2.values = NULL,
  centered = "none",
  data = PMD,
  cond.int = FALSE,
  johnson_neyman = TRUE,
  jnplot = FALSE,
  jnalpha = 0.05,
  robust = FALSE,
  digits = getOption("jtools-digits", default = 2),
  pvals = TRUE,
  confint = FALSE,
  ci.width = 0.95)
```
````

Excerpt of the code used to test mediations:

````
## Mediatior: PRMQ1 (based on regression main effects)
### IV: PHQ9
```{r}
model.M <- lm(PRMQ1 ~ PHQ9 + Gender1 + Age, data = PMD)
model.Y <- lm(Accuracy ~ PRMQ1 + PHQ9 + Gender1 + Age, data = PMD)
results_nomod <- mediation::mediate(model.M,
                              model.Y,
                              treat =  "PHQ9",
                              mediator= 'PRMQ1',
                              boot=TRUE, sims=10000)
summary(results_nomod)
```
````

Excerpt of the code used to test moderated mediations:

````
### PHQ9
```{r}
## Remove age as a covariate to resolve issues with multicollinearity/over fitting

model.M <- lm(PRMQ1 ~ PHQ9_c + Gender1, data = PMD)
model.Y <- lm(Accuracy ~ PRMQ1 + PHQ9_c * N300_c + Gender1, data =PMD)
results <- mediation::mediate(model.M,
                    model.Y,
                    treat =  "PHQ9_c",
                    mediator= 'PRMQ1',
                    boot=TRUE, sims=10000)
summary(results)
```

# Conditional indirect mediation effects not controlling for age
## Create different levels of moderator
```{r}
# Average N300 value
N300_c <- PMD$N300_c
mean_N300_c <- mean(PMD$N300_c)
PMD$mean_N300_c <- mean_N300_c

N300_c <- PMD$N300_c
sd_N300_c <- sd(PMD$N300_c)
PMD$sd_N300_c <- sd_N300_c

# +1 SD
sd_N300_c <- PMD$sd_N300_c
mean_N300_c <- mean_N300_c
plus_N300_c <- mean_N300_c + sd_N300_c
PMD$plus_N300_c <- plus_N300_c

# -1 SD
sd_N300_c <- PMD$sd_N300_c
mean_N300_c <- mean_N300_c
minus_N300_c <- mean_N300_c - sd_N300_c
PMD$minus_N300_c <- minus_N300_c
```

## PHQ9
### -1 SD
```{r}
model.M <- lm(PRMQ1 ~ PHQ9_c + Gender1, data = PMD)
model.Y <- lm(Accuracy ~ PRMQ1 + PHQ9_c * minus_N300_c + Gender1, data =PMD)
````
````

````
resultsP1 <- mediation::mediate(model.M,
                         model.Y,
                         treat =  "PHQ9_c",
                         mediator= 'PRMQ1',
                         boot=TRUE, sims=10000)
summary(resultsP1)
```
````
````