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Disentangling the Relations between Acute Stress, Chronic Stress, and Prospective Memory

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Given the importance and prevalence of Prospective Memory (PM) in daily life and the common experience of stress, it is critical to understand the relations between them. Despite a growing literature base, the answers to some of the simplest questions about these relations remain unanswered. The present study was designed to investigate the relations between both acute and chronic stress and time- and event-based PM. Several methodological features make this study unique and may contribute to a broadening of our understanding of PM in daily life. The results of the present study revealed that chronic stress was negatively correlated with strategic clock monitoring and time-based PM. On the other hand, chronic stress measures did not correlate significantly with either focal or non-focal event-based PM. Acute stress was not correlated with significant differences in PM performance. Prospective memory performance was not significantly correlated with time of day, nor did time of day help to account for the general null findings between acute stress and PM abilities. Continuing to explore the nuanced ways in which stress and PM interact will clarify whether different types of stress can be beneficial or detrimental to one's ability to complete intentions in the future, and under what conditions.

Keywords: Stress, Prospective Memory, Intentions, Event-based, Time-based

Disentangling the Relations Between Acute Stress, Chronic Stress, and Prospective Memory

Introduction

Everyone is familiar with stress – a phenomenological state of altered physiology that can influence feelings, thoughts, and behaviors. These changes can foster peak performance or episodes of overwhelming pressure. Whether stress comes from an impending presentation, too many tasks on one's schedule, an inundation of pressure from work, or other sources, it is a ubiquitous human experience (Asmundson & Taylor, 2005; Baum, 1990). The World Health Organization (WHO), in their 2001 report on mental health, identified stress as one of the most significant health concerns of the 21st century (World Health Report, 2001). Although stress can certainly contribute to mental and physical health concerns, stress has complex relations with the vitality of the body and functioning of the brain. Stress can also have adaptive value, enabling one to perform at optimal levels relative to its absence, as described by the Yerkes-Dodson law (1908) and other researchers (Born, Hitzler, Pietrowsky, Pauschinger, & Fehm, 1988; Lupien, Maheu, Tu, Fiocco, & Schramek, 2007).

Stress first entails an activating agent or event, also known as a *stressor*, that threatens to, or removes, an organism from homeostasis. The presence of a stressor then initiates the *stress response*, or an organism's physiological and accompanying cognitive, emotional, and behavioral reactions to a stressor, aimed to address the stressor and reestablish equilibrium (Clark, Bond, & Hecker, 2007; Hoes, 1986; Lupien et al., 2007; Selye, 1975; 1998). Stressors can be absolute or relative, such that absolute stressors are real threats to one's well-being (e.g., a natural disaster such as an earthquake) and evoke the stress response among all individuals involved, while relative stressors require cognitive appraisal and may not induce the same type of stress response among individuals, or any stress response at all (Lupien et al., 2007; 2006).

For example, some individuals find taking exams to be debilitatingly stressful, while others relish the opportunity to perform in such conditions.

When a stressor evokes a stress response, two distinct axes activate. The sympathetic-adrenal-medullary (SAM) axis initiates, releasing catecholamines (e.g., adrenaline and noradrenaline), and the hypothalamic-pituitary-adrenal (HPA) axis creates a cascading reaction of stress hormones such as corticotropin-releasing hormone (CRH) from the periventricular nucleus of the hypothalamus, adrenocorticotropin hormone (ACTH) from the pituitary gland, and glucocorticoids (GCs; also called cortisol in humans) from the adrenal cortex that mobilize energy for fight-or-flight responses (Lupien et al., 2007; 2006; Sapolsky, Romero, & Munck, 2000). Basal levels of stress mediators, such as catecholamines and cortisol, secrete following a diurnal rhythm, coordinated by light-dark and sleep-wake cycles. These basal levels tend to culminate in the early morning (the circadian peak), slowly decrease throughout the day until an evening low-level concentration period (the circadian trough), and then rapidly rise during the early hours of sleep (McEwen, 2000; Lupien et al., 2007; Lupien et al., 2002; Van Cauter & Turek, 1994). The induction of stress mediators, beyond basal levels, has both adaptive and protective as well as harmful effects (McEwen, 2000; 1998b).

The stress response divides into two types based on its temporality: acute stress and chronic stress. Acute stress describes a short-term stress response evoked by a temporary stressor, whereas chronic stress denotes long-term, enduring stress induced by a single persisting stressor or multiple stressors over time (Lupien et al., 2007; Shields, Sazma, & Yonelinas, 2016; Timko, Moos, & Michelson, 1993). Acute and chronic stress responses vary in how they impact health and cognitive abilities. Although the search for the biological mechanisms leading to protective versus harmful impacts of stress continues, the temporality of the stress response is a crucial factor in this determination. For example, in the short term, stress mediators increase the available energy in various bodily substrates and facilitate optimal adaptations to the changing environment. Conversely, prolonged circulation of stress mediators, such as highly catabolic GCs (that antagonize insulin and increase blood pressure), can lead to elevated risk of diabetes, hypertension, brain changes, impaired tissue growth and repair, increased risk of infection, as well as other stress-related diseases (Juster, McEwen, & Lupien, 2010; Lupien et al., 2007). In parallel with physiological modifications, the experience of both acute and chronic stress (above and beyond basal levels) can augment, or in some instances, impair, cognitive functioning, including memory (Lupien et al., 2007; Roozendaal, 2002).

Stress and Retrospective Memory. Memory bisects into two broad forms: retrospective and prospective. Retrospective memory (RM) refers to the explicit recall of information about past events and contrasts with prospective memory (PM), which refers to remembering to do something in the future. The majority of research into stress and memory has focused on RM. Het and colleagues (2005) reveal that most studies document memory impairments due to chronic circulating GCs, while studies of acute GC treatment show mixed results (Belanoff, Gross, Yager, & Schatzberg, 2001; Het et al., 2005; McEwen & Sapolsky, 1995; Wolf, 2003). Shields, Sazma, McCullough, and Yonelinas (2017), through meta-analytical and integrative review, note that an important consideration when predicting the effects of acute stress on memory abilities is where stress induction occurs in the memory process (i.e., stress induction occurring before or after encoding, storage, and retrieval). For example, when acute stress responses take place shortly after learning information (i.e., post-encoding stress), it can enhance information retention (Andreano & Cahill, 2006; Beckner, Tucker, Delville, & Mohr, 2006; Roozendaal, 2002; Smeets, Otgaar, Candel, & Wolf, 2008).

The effects of acute stress on encoding are somewhat equivocal, as studies show both beneficial effects (Payne et al., 2007; Smeets, Giesbrecht, Jelicic, & Merckelbach, 2007; Smeets et al., 2008) and deleterious effects (Maheu, Collicutt, Kornik, Moszkowski, & Lupien, 2005; Payne et al., 2007) of acute stress on encoding and consolidation processes. A prevailing theory that can accommodate these varied findings comes from Roozendaal (2002), according to which the relations between acute stress and RM follow an inverted-U-shape dose-response curve, mirroring the Yerkes-Dodson law (1908). According to the model, insufficient or excessive stress levels impair RM (i.e., levels that are at the extremes of the inverted U), while moderate doses of stress, or “optimal” levels (i.e., those at the top of the inverted U), enhance RM. Due to the circadian rhythm of stress levels, this model, in conjunction with the model of a circadian cortisol effect (Lupien & McEwen, 1997), predicts RM impairments from cortisol treatment during the morning hours, when stress levels are at their highest, and RM enhancement from cortisol treatment in the evening hours, when levels are more optimal. A meta-analysis of studies that contain data on stress induction in varying hours of the day supported these models. Additionally, these analyses showed that on average, cortisol impaired memory retrieval, with a medium ($d = -.49$) effect size (Het et al., 2005; see also Smeets, 2011).

Studies on how stress modifies functioning in the brain areas that support memory processes are consistent with the previously described patterns. Specifically, stress influences the functioning of medial temporal lobe (MTL) structures, such as the hippocampus, because of high concentrations of GC receptors. Accordingly, GCs can facilitate hippocampus-supported consolidation processes, as well as inhibit hippocampus-dependent memory retrieval (Roozendaal, 2000; 2002; Roozendaal, Griffith, Buranday, de Quervain, & McGaugh, 2003). Chronic stress can contribute to hippocampal dysfunction, including decreased overall volume, neuronal degeneration, deficient synaptic efficiency, and impairments in glucose utilization (Ferris & Stolberg, 2010; Lupien et al., 2005; 2007). The amygdala contains a moderate density of GC receptors (Honkaniemi et al., 1992), and can modulate memory consolidation in other brain areas, including the hippocampus, when stimulated by emotionally-charged experiences (McGaugh, Cahill, & Roozendaal, 1996; McGaugh, Ferry, Vazdarjanova, & Roozendaal, 2000), as the amygdala mediates the catecholamine influences on memory consolidation (Cahill & McGaugh, 1991; Roozendaal, 2002).

Stress also influences frontal regions of the brain, including the prefrontal cortex (PFC). For instance, research shows that acute stress can impair PFC functioning, especially when feeling a lack of situational control (Arnsten, 2000; 2009; 1998; Cerqueira, Mailliet, Almeida, Jay & Sousa, 2007; Lupien & Lepage, 2001; Qin, Hermans, van Marle, Luo, & Fernandez, 2009). The PFC forms functional connections with many cortical and subcortical areas of the brain, and supports many cognitive abilities, such as emotion regulation, management of thought and action, and executive functions, including those related to encoding and retrieval (Arnsten, 2009; Diamond, Campbell, Park, Halonen, & Zoladz, 2007; Miller & Cohen, 2001; Schwabe, Joëls, Roozendaal, Wolf, & Oitzl, 2012). However, the effects of stress on the PFC differ by subregion, and therefore, these functions likely have differential robustness of stress modification (Mika et al., 2012). Exposure to chronic stress creates more insidious alterations in the architecture of the PFC than acute stress, such as dendritic spine density changes and disturbances in the connectivity necessary for memory consolidation (Arnsten, 2009; Holmes & Wellman, 2008; Radley et al., 2006).

Although the literature base highlights some influences of the primary mediators of stress independently, they do not create functional alterations in the brain and cognition in isolation.

For instance, epinephrine can enhance consolidation and long-term retention (Gold & Van Buskirk, 1975; 1978). Given that epinephrine does not easily cross the blood-brain barrier, its enhancing effects on memory appear to initiate, at least partially, by β-adrenoceptors located in the periphery (Introini-Collison, Saghafi, Novack, & McGaugh, 1992; Weil-Malherbe, Axelrod, & Tomchick, 1959). Yet, the beneficial effects of epinephrine on memory also rely on noradrenergic activation in the basolateral amygdala (Liang et al., 1986; Roozendaal et al., 2008). The GC effect on memory consolidation also depends on noradrenergic activation in the basolateral amygdala (Roozendaal, 2002), as blocking noradrenergic activity in this area also blocks the GC effect on memory (de Quervain, Aerni, & Roozendaal, 2007; Diamond et al., 2007; Schwabe et al., 2012). As documented, the primary mediators of stress work with one another, and in various memory-related brain structures, to foster changes in memory processes. This remains most evident in RM processes, such as episodic memory (Shields et al., 2017).

Prospective Memory

Prospective memory is a future-oriented memory system that entails remembering to complete planned actions or intentions. The ability to complete intended actions, often after a delay, is fundamental for functioning in everyday life (Brandimonte, Einstein, & McDaniel, 1996; Einstein & McDaniel, 1990; 1996; Ellis, 1996; McDaniel & Einstein, 2007). People can associate intentions with aspects of time (time-based PM), such as a specific time or intervals of time, as well as environmental cues (event-based PM), including locations, objects, people, or the conclusion of events (Einstein & McDaniel, 1990; 2005). Common examples of time-based PM include remembering to attend an appointment or meeting at 10:00 am or remembering to renew the time on a parking meter after the passing of an hour. One utilizes event-based PM when remembering to tell a friend or colleague an important message when you see them next or to make a phone call after a meeting concludes.

Prospective memory incorporates RM in that one must recall a previously formed intention to complete the PM. However, several key features distinguish PM from RM (Einstein & McDaniel, 1990; 1996; McDaniel & Einstein, 2000). First, in tasks of prospective remembering, participants typically engage in an unrelated ongoing activity and may need to monitor the environment for the appropriate time or context in which to perform an intended action. Experimental tasks of RM lack an ongoing task, but rather, involve asking participants to recall previously presented information. By requesting participants to recall details of previously presented information (e.g., a word list or narrative), subjects enter what Tulving (1983) refers to as “retrieval mode.” In contrast, retrieval of intentions within a PM task ensues without external prompting (i.e., there is no direct request to retrieve intentions), requiring some degree of self-initiation. Upon identification of a PM cue, one must inhibit the allocation of attentional resources towards an ongoing activity, and switch attention from the ongoing task to the PM task (Einstein, Holland, McDaniel, & Guynn, 1992; Einstein & McDaniel, 1990; 1996; Smith, 2003; Smith & Bayen, 2004). Researchers often refer to these additional unsolicited cognitive processes as “self-initiated processing” (Craik, 1986).

Both time-based and event-based PM rely on self-initiated processing (Brandimonte et al., 1996; Kliegel et al., 2001). However, these two forms of PM differ in the degree to which they rely on self-initiated processing (d’Ydewalle, Bouchaert, & Brunfaut, 2001; McDaniel, Einstein, & Rendell, 2008). For instance, because time-based PM lacks externally presented cues to signal appropriate retrieval of previously formed intentions, this form of PM relies more on self-initiated activity (e.g., monitoring the time) than event-based PM (d’Ydewalle et al., 2001;

Einstein & McDaniel, 1990; Kliegel et al., 2001). Kliegel et al. (2001) provided evidence supporting the idea that time-based PM requires additional self-initiated processing and allocation of attentional resources by demonstrating that the importance of a PM task affects time-based but not event-based PM task performance. Specifically, the authors found a significant importance effect in monitoring responses, such that participants in the high importance condition monitored the clock more frequently. The authors concluded that importance impacted time-based PM performance to a higher degree than event-based PM performance due to increased requirements of self-initiated strategic rehearsal and monitoring of the environment for the presence of a time-based target cue (Kliegel et al., 2001).

Time-based PM tasks characteristically require the execution of a PM intention at precise moments in time, such as by pressing a button after a certain time interval elapses (e.g., three-minute intervals), while at the same time performing an ongoing task (Brandimonte et al., 1996; Kliegel et al., 2005; McDaniel & Einstein, 2007; Smith, 2003). In such tasks, one must monitor the passage of time to determine if a specified amount of time has elapsed (Einstein & McDaniel, 1990; Harris & Wilkins, 1982; McFarland & Glisky, 2011; 2009). On the other hand, event-based PM tasks customarily involve execution of a PM intention (e.g., pressing a button) when an associated external cue is presented, such as a target word, embedded within an ongoing task (Brandimonte et al., 1996; Kliegel et al., 2005; McDaniel & Einstein, 2007; Smith, 2003). Monitoring for the presence of an event-based cue may still be required for successful PM, however, depending upon several factors, including ongoing task difficulty, cue salience, the number of target events, and individual differences such as age and health status (Einstein et al., 2005; McDaniel & Einstein, 2000; Scullin, McDaniel, & Einstein, 2010).

Event-based tasks also depend upon self-initiated processing, but the amount of required cognitive resources depends on the focality of the cues. Focality refers to the degree to which an ongoing task facilitates the processing of the event-based PM cue (Einstein et al., 2005; McDaniel & Einstein, 2007). For example, if one has an intention to go to the gym after work and passes the gym on the road while driving home, thus activating the retrieval of the intention, then the gym posed as a focal event-based cue, requiring little active monitoring for event-based cue detection. However, if in the same scenario, the gym was not on the way home from work or obscured from view, then one would need to actively maintain the intention and anticipate the point where one needs to turn to get to the gym on the way home. Therefore, the less focal an event-based cue, the more self-initiated resources one requires for cue detection and intention retrieval (Einstein et al., 2005; Kliegel, Jäger, & Phillips, 2008; McDaniel, Shelton, Breneiser, Moynan, & Balota, 2011). In the laboratory, a focal task can entail performing an action (e.g., pressing a button) when identifying a target word (e.g., the word “candle”) in an ongoing activity, whereas a non-focal laboratory-based task might involve searching for a syllable or arrangement of letters (e.g., the syllable “tor”) inside a word, making the non-focal cues more difficult to identify.

Researchers debate the extent to which PM requires active monitoring, such that some argue that in particular cases (e.g., encountering a focal event-based cue), monitoring is not required, and spontaneous retrieval of an intention associated with the cue can occur (multiprocess theory; see McDaniel & Einstein, 2000), while others argue that monitoring is a requirement for all prospective remembering (preparatory attentional and memory processes theory; see Smith, 2003; Smith & Bayen, 2004). The demands that PM tasks place on self-initiated processing recruits various executive functions, in addition to RM. Executive functioning is a term that refers to goal-directed processes that enable one to monitor the environment, switch between tasks or stimuli (shift), plan, maintain information in working memory (WM), and inhibit actions or responses (Martin, Kliegel, & McDaniel, 2003; Salthouse, Berish, & Siedlecki, 2004; Schnitzspahn, Stahl, Zeintl, Kaller, & Kliegel, 2013).

Prospective memory tasks entail five distinct phases, each of which depends, to varying degrees, on intact executive functioning and memory processes, as well as the neural systems that support those processes. These phases include: (1) *development phase* – where intention formation and action plan development take place, (2) *maintenance/monitoring phase* – the period in which one maintains an intention in long-term memory while engaged in an unrelated ongoing task; one may also engage in monitoring for PM cues during this phase, (3) *retrieval phase* – the point at which one recognizes a PM cue (e.g., time or event) and retrieves the related intention, (4) *inhibition phase* – where one inhibits ongoing activity to execute the PM task, and (5) the *execution phase* – when one executes the intended action (McFarland & Vasterling, 2017; for alternative models see, Ellis, 1996; Kliegel, Martin, McDaniel, & Einstein, 2002).

The five phases of PM rely on a frontoparietal executive control system and the MTL declarative memory system to differing degrees. For example, the development phase likely relies more on executive control systems to form an intention and create a plan for that intention (e.g., planning how and at what point to act on the intention). Although the development phase also relies on RM, in that one must recall what completing the intention requires and a scenario where one could complete the intention, it depends to a lesser extent upon RM systems. In the maintenance/monitoring phase, the reliance divides more evenly across executive control processes and RM systems, in that target cues necessitate maintenance by the MTL system while one engages in unrelated ongoing activity. Simultaneously, the frontoparietal executive control system may also rehearse the intention and monitor the environment for PM cues while allocating cognitive resources towards ongoing tasks (McFarland & Vasterling, 2017).

The retrieval phase mainly involves recognition of intention-relevant cues (e.g., events or times associated with intentions) and retrieval of intentions; thus, this phase relies heavily on the MTL system. The frontoparietal system can also support this phase, where if a weak association became established in the planning phase, then the frontoparietal system can engage in effortful/strategic searching for intentions associated with a cue. When cue recognition and intention retrieval take place, one must shift attentional resources from the ongoing task in favor of completing PM intentions. This involves the inhibition phase, dominated by executive control processes. The execution phase occurs after one inhibits resource allocation from the ongoing task in favor of PM task completion, and the frontoparietal executive control system initiates the actions involved with successful PM completion (McFarland & Vasterling, 2017). Given that stress impacts both the retrospective and executive functioning processes on which PM depends, one could theorize that stress also influences PM performance.

Acute Stress and Prospective Memory. In contrast to the extensive research base that delineates the relations between stress and RM, a relatively small amount of research exists investigating the relations between stress and PM. Thus, some of the most basic questions about stress and PM remain unanswered. Piefke and Glienke (2017) provided a systematic review of the available research and described themes regarding the literature base on the relations between stress and PM. One of the several emergent themes pertained to variations in stress induction methods. Some studies investigated the influence of basal levels of stress (Nakayama, Takahashi, & Radford, 2005), induced acute stress using the Trier Social Stress Test (Nater et al., 2006; Walser, Fischer, Goschke, Kirschbaum, & Plessow, 2013) or the Socially Evaluated Cold Presser

Test (SECPT; Glienke & Piefke, 2016), self-reported stress levels (Ihle et al., 2012; Schnitzspahn et al., 2011), and work-related stress (Eskildsen, Andersen, Pedersen, Vandborg, & Andersen, 2015), on PM abilities. The use of varying methods of stress induction makes it difficult to arrive at consistent conclusions in the area. For example, studies of the impact of acute stress on PM show that acute stress can enhance time-based PM (Nater et al., 2006), has no relations with event-based PM (Nater et al., 2006; Walser et al., 2013), and can enhance both time- and event-based PM (Glienke & Piefke, 2016).

Möschl, Walser, Plessow, Goschke, and Fischer (2017) conducted a study that aimed to increase the demands of PM tasks to identify if such tasks could create demands that stress would noticeably influence. To accomplish this, the authors used non-focal event-based cues (the letter sequence “TRA”) in an ongoing task that involved categorizing words as nouns or verbs. They also used a two-condition (high versus low PM load) to target different degrees of PM processing. In the low load condition, participants monitored for the TRA letter sequence, while in the high load condition, participants monitored for any permutation of the letters A, C, and K (e.g., Jack). In another condition, they employed focal event-based cues, where participants searched for words presented in a distinctive color. To evoke acute stress among participants, they used the original Trier Social Stress Test (TSST; Kirschbaum, Pirke, & Hellhammer, 1993) paradigm. Half of the participants underwent the TSST, including an anticipatory period, simulated job interview, and mental arithmetic task completed in front of confederates, while the other half completed these without performing in front of observers (i.e., a placebo TSST). They also collected salivary cortisol samples to validate their stress induction procedures.

Möschl et al. (2017) reported that acute stress did not influence PM performance in either focal or non-focal conditions. They also found that stress did not affect monitoring behavior in the focal condition, but that stress affected monitoring substantially in the non-focal condition. They summarized their findings by stating that acute stress did not affect PM abilities when demand was low, but that acute stress led to significant reductions in monitoring costs for PM cues when demands were high. Thus, acute stress may have led to a shift in strategy towards resources-conserving behaviors, increasing the efficiency of event-based PM performance. Due to their focus on event-based PM, the authors did not measure time-based PM. This is noteworthy because the literature clearly distinguishes between time- and event-based PM, with time-based PM potentially requiring more self-initiated processing that could be susceptible to the influence of acute stress (e.g., Nater et al., 2006). Although this study provides novel data that adds to the limited literature on acute stress and event-based PM, these variables require additional investigation to specify the conditions in which stress impacts various PM abilities.

Szőllősi, Pajkossy, Demeter, Kéri, & Racsmány (2018), contributed to the literature base examining the relations between acute stress and PM by testing whether acute stress influences PM performance through modification of executive functioning abilities or associative memory processes. In their study, they used a time-based PM task and two event-based tasks designed to measure differences in required executive demands. Despite significant elevations in acute stress levels through their use of SECPT protocol, there was no significant impact of acute stress on time-based PM (clock checks or the number of hits) or verbal fluency. However, acute stress enhanced event-based PM performance (as measured by reaction times for PM cues and ongoing cost). Acute stress did not influence event-based PM performance differentially between the two tasks of differential demands, indicating that acute stress may not have noticeably impacted the executive abilities required for successful event-based PM. For example, stress did not affect the ongoing activity cost, thought to reflect monitoring (Smith, 2003). Additionally, stress did not alter participant verbal fluency ability, also thought to tap into various executive processes. The authors concluded that event-based PM may rely on associative memory processes more than time-based PM because successful time-based PM always relies on self-initiated executive control processes, and given that acute stress modified event-based PM response time and did not affect time-based PM performance, participants engaged in more automatic associative responding (Szőllősi et al., 2018). While these findings are somewhat at odds with other studies that found no relations between acute stress and event-based PM (e.g., Nater et al., 2006; Walser et al., 2013), this study suggests that associative memory processes (i.e., the retrospective component of PM) may play a crucial role in event-based PM.

Recently, Cuttler and colleagues (2019) conducted a study that focused on the effects of acute and chronic stress on single delay (episodic) and recurring (habitual) event-based PM performance among chronic cannabis users. They did not include measures of time-based PM in this study. The authors predicted that because chronic cannabis users may have diminished stress reactivity, acute stress would not contribute to benefits in event-based PM performance. To induce stress, they used the Maastricht Acute Stress Test (Smeets et al. 2012), where they combined aspects of cold pressor and social stress tests. Independent and combined examination of the effects of stress and cannabis use on event-based PM performance revealed that acute stress responses impaired event-based PM performance among their overall sample (i.e., a combination of cannabis users and non-users). The authors suggested that the use of a severe multidimensional stress inducer that includes aspects of both the SECPT and the TSST potentially led to excess levels of acute stress among those in the study, and if stress levels and PM performance follow an inverted U-shaped dose-response pattern, then the levels on the far end of the inverted U led to PM performance decrements. This was the first study to document adverse effects of acute stress on PM performance, so other possible explanations followed. For example, this study induced stress after intention encoding, and is one of the only studies to incorporate this methodology (with exception to Walser et al., 2013). Also, their inclusion of a sample of cannabis users, with possible dampened stress reactivity, may have negated some of the beneficial effects of acute stress (Cuttler et al., 2019).

Although there is a growing body of research investigating the relations between acute stress and PM, as well as possible mechanisms of modification (e.g., response times and monitoring), key stress- and PM-related variables remain neglected in the larger picture. Notably, most studies did not consider the time of day during which testing of participants took place or tested participants only during a particular period of the day (e.g., in the afternoon). Time of day is a variable that correlates with basal levels of the primary mediators of stress, such as cortisol levels (Lupien et al., 2007). Given the growing evidence that suggests the relations between acute stress and PM follow an inverted U-shaped dose-response pattern (Cuttler et al., 2019; Marchant, Trawley, & Rusted, 2008, time of day is a variable that warrants attention.

Where stress induction occurs in the PM sequence (i.e., before, during, or after intention encoding, retrieval) also appears to be an important consideration when examining relations between stress and PM (Shields, Sazma, McCullough, & Yonelinas, 2017). For instance, Glienke and Piefke (2017), after reanalysis of the data from their previous study (Glienke & Piefke, 2016), showed that induced acute stress before the planning phase of PM (especially among those with low cortisol responsivity) contributed to improved PM performance that remained stable over time. In most of the studies comprising the literature (e.g., Glienke & Piefke, 2016; 2017; Möschl et al., 2017; Nater et al., 2006), intention encoding and retrieval occurred after stress induction. While they demonstrate that encoding and retrieval of intentions might remain preserved, or even enhanced, under these acute stress conditions, they do not examine how stress influences PM abilities when stress induction occurs after the formation of PM intentions. Among the two studies that investigated the impact of stress after PM intention formation (e.g., Cuttler et al., 2019 and Walser et al., 2013), the results are mixed. Therefore, the literature base necessitates additional studies that include variations in the point at which acute stress induction occurs in the process of PM to gain a comprehensive understanding of these relations.

Chronic Stress and Prospective Memory. Studies of the effects of chronic stress on PM, although as of now studied less than acute stress-PM relations, contain more consistent and directional results. Most of the research in the area suggests that chronic stress can impair PM performance (Eskildsen et al., 2015; Glienke & Piefke, 2017; Ihle et al., 2012; Schnitzspahn et al., 2011). Ihle and colleagues (2012) and Schnitzspahn et al. (2011), using self-rating scales of perceived stress over five days (averaged across days), revealed a significant negative correlation (r = -0.36) between everyday stress composite scores and naturalistic PM performance. Similarly, Eskildsen and colleagues (2015) examined the influences of work-related stress on cognitive test performance among a large sample of outpatient individuals. The authors found that three pronounced impairments separated those with perceived work-related stress and those without. These impairments emerged on a self-made measure of event-based PM, processing speed, and performance on the PASAT, a test that measures aspects of working memory (WM), sustained attention, arithmetic abilities, and speed. One caveat to these findings comes from a study by Ihle et al. (2014), where they found that greater perceived stress reported by participants at the outset of their study, thought to measure chronic stress rather than experimentally induced acute stress, correlated with enhanced clock monitoring and time-based PM performance.

McLennan, Ihle, Steudte-Schmiedgen, Kirschbaum, and Kliegel (2016) examined how concentrations of hair cortisol interacted with various aspects of cognition among working adults. They aimed to use hair cortisol concentrations (HCC) as a way of measuring chronic stress integrated over months, rather than by measurement of salivary GCs, as the latter can modify by diurnal rhythm or momentary stress increases. The measures of cognition they included were that of memory (including PM), WM and executive functions, as well as other variables such as inductive reasoning, crystallized intelligence, and cognitive speed. They assessed both focal and non-focal conditions embedded within an ongoing 2-back task. They did not provide many details surrounding the PM task, or PM performance. The results of the study demonstrated that HCC did not associate significantly with any of the cognitive measures, including PM (McLennan et al., 2016). However, they measured only event-based PM. As previously mentioned, because of the potentially higher demands of time-based PM, this form may be more susceptible to the influence of stress, including chronic (e.g., Ihle et al., 2014).

The previously described study by Cuttler et al. (2019) also included measurements of chronic stress as they related to episodic and habitual event-based PM tasks among the sample of chronic cannabis users and non-user controls. To assess chronic stress, they included the Perceived Stress Scale (PSS; Cohen, Kamarck, & Mermelstein,1983). They also included baseline measures of stress, such as salivary cortisol levels and subjective stress levels. When relating their measures of chronic stress with event-based PM performance, they discovered a significant negative correlation between PSS scores and episodic event-based PM, $r = -0.31$, $p = .005$. The authors also found that subjective stress levels associated negatively with event-based PM performance. The results of this study were in line with the small number of studies in the area suggesting that chronic stress can lead to event-based PM impairments (Eskildsen et al., 2015; Ihle et al., 2012; Schnitzspahn et al., 2011). However, many studies lack the assessment of both chronic stress and time-based PM, leaving a large gap in the literature and limiting the ability to make conclusions about chronic stress and time-based PM.

Although there has been growth in our understanding of stress and PM relations, differing methodology (e.g., stress type, PM tasks) and other factors make it difficult to render definitive conclusions. Another limitation in the field is the lack of accounting for differing types of stress and their relations with PM. For instance, few studies investigating how acute stress impacts PM also assessed chronic stress levels before stress induction. It is important to quantify and account for both acute and chronic stress because they are dissociable stress types, and chronic stress can potentially influence PM abilities (Eskildsen et al., 2015; Ihle et al., 2012; Schnitzspahn et al., 2011). Thus, attempting to account for the influence of both types of stress may allow better identification of how acute and chronic stress impact PM abilities independently from one another or through their interrelations.

Conceptual Framework of the Relations Between Stress and Prospective Memory

The existing literature suggests that the nature of the relations between stress and PM performance depends on several factors, including the type of stress, type of PM, and others, such as where stress induction occurs in the memory process. Acute and chronic stress can modify PM through several mechanisms. The integration of the Easterbrook hypothesis (1959) and the Yerkes-Dodson law (1908) explains one possible mechanism, where arousal levels can modulate attentional selectivity. In this view, participants with optimal levels of arousal may assign higher attentional weights to identify target stimuli and have improved ability to detect target cues among distractors, such as in an ongoing task (Sørensen & Barratt, 2014; Sørensen, Vangkilde, & Bundesen, 2014).

Regarding the mechanisms of acute stress, when acute stress induction occurs before the planning phase of a PM intention, it can modulate PM performance for both event-based and time-based PM, creating enhanced and stable PM performance across time (Glienke & Piefke, 2016; 2017). Glienke and Piefke (2016; 2017) demonstrate that acute stress can enhance PM through increased memorization and recall of PM intentions over time. Further, Möschl et al. (2017) and Szőllősi et al. (2018) reveal that acute stress can modulate event-based PM performance efficiency, such as by decreasing reaction time to event-based cues and by creating significant reductions in monitoring costs. Nater et al. (2006) also highlighted the monitoring benefits of acute stress for time-based PM, such that acute stress augmented monitoring for time-based cues, and in turn, enhanced time-based PM performance. In summary, acute stress can enhance both the retrospective and executive processes necessary for both time- and event-based PM success under certain conditions.

The only study documenting a negative relation between acute stress and PM was by Cuttler et al. (2019). In that study, they induced stress after PM intention formation. Walser et al. (2013) conducted a study with a similar methodology but instead found no significant relations between acute stress and PM performance. One potential reason for the difference is that Cuttler et al. (2019) used a multidimensional stress induction method, combining aspects of the TSST and SECPT, possibly inducing higher levels of acute stress, resulting in impaired PM performance. Another factor was that Walser and colleagues (2013) used only focal event-based PM cues that may have obviated the necessary cognitive resources that stress influences (e.g., monitoring). Therefore, acute stress may have benefits to event-based PM under specific conditions, such as: when levels are optimal, when PM demands are high, and especially when induced before the planning phase. This pattern of findings suggests an interaction between stress levels, the requirements of cognitive resources, and the phase at which stress induction occurs in the memory process. Importantly, neither Walser et al. (2013) nor Cuttler et al. (2019) included measurement of time-based PM, so it remains unclear if this interaction holds with time-based PM.

Examinations of the relations between chronic stress and PM show that chronic stress tends to correlate negatively with the cognitive processes that lend to successful PM performance, including memory retrieval. Consistent with this research are studies highlighting the harmful impact of chronic stress on the brain structures that support these processes. For instance, chronic stress can impair hippocampal function and lead to decreased overall volume, neuronal degeneration, diminished synaptic efficiency, and inefficient glucose utilization (Ferris & Stolberg, 2010; Lupien et al., 2005; 2007). Chronic stress creates more insidious modifications in PFC architecture and functioning than acute stress, including dendritic spine density changes and disturbances in the connectivity required for memory consolidation (Arnsten, 2009). Overall, chronic stress has the potential to harm the brain areas, and in turn, the supported functions, necessary for PM success. In parallel, the literature in the area of chronic stress and PM suggests that chronic stress can impair underlying mechanisms of event-based PM performance. However, the study by Ihle and colleagues (2014) suggests that the relations between chronic stress and PM may not be simply harmful, as in this study, perceived stress (likely reflecting chronic stress levels brought into the study) correlated with enhanced clock monitoring behavior and time-based PM. This study, in conjunction with our previous unpublished study data (See "Previous Study Findings" section below), raises the possibility that the nature of the relations between chronic stress and PM performance (whether beneficial or detrimental) depends on the chronic stress levels, rather than only if stress levels are enduring. The literature base requires further research to gain a better understanding of these relations, as most studies do not quantify and account for both chronic and acute stress. Additionally, the literature includes almost no investigations of how chronic stress influences laboratory time-based PM, with the lone exception being Ihle et al. (2014). Future research can assist in delineating the relations between PM and acute stress and chronic stress by using consistent methodology.

The Trier Social Stress Test. The Trier Social Stress Test (Kirschbaum, Pirke, & Hellhammer, 1993) is a widely utilized method for inducing acute stress responses among individuals, and it has high reliability and effect sizes (Kirschbaum et al., 1993; Payne et al., 2007; von Dawans, Kirschbaum, & Heinrichs, 2011). The TSST is a performance task that first involves a three-minute preparation period, a five-minute oral presentation performed in front of trained confederates, and lastly, a five-minute mental arithmetic task (also performed in front of the confederates), bringing the total time of the TSST administration to around 13 minutes. Although primary stress mediators vary throughout the day because of the circadian rhythm of stress, exposure to the protocol can evoke reliable acute stress reactions among individuals (Kudielka, Hellhammer, & Kirschbaum, 2007; Kudielka, Schommer, Hellhammer, & Kirschbaum, 2004). However, a rest period should precede the protocol to minimize prior stressful events or other confounding factors.

Kelly, Matheson, Martinez, Merali, and Anisman (2007) examined if participants who undergo the TSST in front of a virtual audience (i.e., the TSST performed through virtual reality) experience elevated cortisol levels when compared to non-stressed participants. They also compared cortisol level elevations among participants who performed the TSST in front of a virtual audience to those who performed the TSST in front of an imaginary audience behind a one-way mirror and a real audience of confederates. The authors found that those who performed in the TSST experienced increased cortisol levels when compared to controls, but notably, the type of audience was important to the amount of stress evoked among participants. Those who performed in the TSST in front of an audience of confederates had cortisol levels that rose 90% above baseline, followed by a 30% cortisol increase among those who performed in the TSST in front of a virtual audience. The imagined audience behind the one-way mirror created the lowest increase in cortisol levels with a 20% increase above baseline (Kelly et al., 2007).

This finding is important because it demonstrates that the type of audience used in the TSST has implications for the maximum potential levels of stress that the paradigm can evoke for participants. The original TSST methodology might also accurately reflect the stress levels evoked by performances in front of live audiences. Some populations, such as college students, might need to present in front of classes or face other acute stressors, such as taking exams (Sherman, Bunyan, Creswell, & Jaremka, 2009). Recurring stressors for college students can also lead to chronic stress (Deroma et al., 2009; Mangold, Veraza, Kinkier, & Kinney, 2007).

College Students, Stress, and Prospective Memory. College students experience considerable levels of stress from various sources (Mangold et al., 2007), including transitioning from high school to college (e.g., living away from home for the first time), adapting to life at college, unexpected social events, work responsibilities, and balancing the many demands required of them (Serlachius, Hamer, & Wardle, 2007). Academic stressors, such as time pressure to turn in assignments, demands from multiple classes, time and money management concerns, and worry over grades, among many others, are particularly notable for this population (Deroma et al., 2009; Garriott & Nisle, 2017; Ross et al., 1999). Some even deem college as the most stressful time in their lives (Hales, 2009). The naturalistic and academic stressors that college students face have effects on the primary mediators of stress. For example, examination stress can lead to increased SAM-axis activity and cardiovascular activation (Loft et al., 2007; Sherman et al., 2009).

Notably, successful navigation of college life also requires the consistent completion of future intentions. For example, college students must remember to attend classes, turn in assignments, take exams, and write papers based on set days and times (i.e., time-based intentions). Further, they also need to complete intentions based on events, such as remembering to respond to emails or talk to professors after class. Balancing events or intentions outside of school, including social events, work schedules, and other responsibilities are also prospective. As described, the many PM demands (academic or other) on college students can also evoke significant stress among this population (Deroma et al., 2009; Garriott & Nisle, 2017; Ross et al., 1999). Given that college can be the most stressful time in life for some, individuals in this phase of life may be at an increased risk for experiencing the impacts of stress.

Previous Findings. Data from an unpublished study investigating the relations between acute and chronic stress and PM among undergraduates revealed differing relations between stress and PM (Stewart & McFarland, under review). Participants either underwent the TSST with an imaginary audience behind a one-way mirror (the experimental group) or completed a word-search activity (the control group), and then completed a computerized PM task to identify if performance differences existed attributable to the induction of an acute stress response. The PM measure included both non-focal event-based and time-based PM tasks. A trivia task served as the ongoing activity. Several noteworthy findings emerged from the study. For one, perceived chronic stress over the past week correlated positively with clock monitoring and increased ability to complete time-based intentions, $r(78) = .293$, $p = .011$, independent of group. Second, although neither acute nor chronic stress correlated with non-focal event-based PM performance, a significant positive correlation emerged between acute stress and non-focal event-based PM among participants who endorsed the highest levels of acute stress, $r(6) = .840$, $p = .009$. Despite the small sample size, this finding raises the intriguing possibility that consistent with a dose-response relation of acute stress and event-based PM, participants with high levels of stress reached “optimal” levels, potentially increasing one’s ability to detect more covert event-based cues in the environment. This aligns with research indicating that high levels of arousal can focus attentional resources towards identifying target stimuli (Sørensen & Barratt, 2014; Sørensen, Vangkilde, & Bundesen, 2014).

Given that we used the modified version of the TSST that demonstrated the lowest elevations in cortisol levels (20% above baseline) when compared with a virtual or real audience (Kelly et al., 2007), it is possible that the amount of stress evoked from the TSST protocol did not reach the levels that noticeably influence PM abilities, except among those who endorsed the highest levels of perceived acute stress. Further, we did not include measures of focal event-based PM, as non-focal event-based PM requires more self-initiated processing that might be more susceptible to the influence of stress. However, the addition of focal event-based PM can help to determine whether a relation between stress and PM emerges as the self-initiated processing demands of a PM task increase. Another limitation regarded the limited data collected on chronic stress. Although we found a significant relation of the measure of chronic stress we used, more information on chronic stress would allow a broader understanding of these relations. The limitations of the extant literature, in conjunction with the goal of replicating and expanding our previous study, formed the basis for the current study.

Objectives and Hypotheses

The objectives of this research were multi-fold. For one, we wanted to replicate and expand on the findings in our previous study with some key methodological differences. We aimed to enable sufficient elevation of stress levels to identify if the relations between acute stress and PM follow an inverted U-shaped dose-response relation by using the original TSST paradigm. Testing participants throughout the day helped to identify if stress induction near the circadian peak and trough created changes in PM abilities following this inverted U-shape function. Increasing the demands of the PM task and adding focal event-based cues assisted in revealing these relations if they exist. Secondly, this study differs from most other studies in the area because stress induction occurred after, rather than before, forming the PM intention. By inducing stress after providing the PM task instructions, this design inserted a delay between the formation of the PM intentions and the execution of those intentions. This modification helped to remove the potentially confounding effects that stress can have on learning (i.e., stress may enhance learning, but diminish PM execution). Therefore, this study tested whether acute stress occurring between intention formation and execution impacts the ability to complete intentions.

Thirdly, we included several measures of chronic stress not only to connect chronic stress and PM performance more generally, but also to account for chronic stress when examining the influence of acute stress on PM performance. This methodology helped to untangle the varied findings on the relations between acute stress and PM. Lastly, we sought to expand on our previous study by adding a measure of self-reported memory ability (i.e., the Prospective and Retrospective Memory Questionnaire) to identify if stress, whether acute or chronic, influences perceived RM or PM ability, as well as general memory ability. For example, do high levels of stress contribute to subjective memory complaints or confidence? Although this was not the primary objective of this study, we also aimed to explore the connection between self-reported memory ability and objective PM performance to identify if stress-related discrepancies existed.

We had several hypotheses for the proposed study. First, we hypothesized that acute stress would enhance PM performance, given the positive correlation between non-focal event-based PM and high stress levels demonstrated by our previous findings, as well as research suggesting acute stress can enhance both event- and time-based PM under certain conditions (Glienke & Piefke, 2016; Nater et al., 2006; Stewart & McFarland, under review). Although there is a shortage in the number of studies that include quantification of chronic stress and laboratory time-based PM performance, the few that exist implicate positive relations between chronic stress and this form of PM (Ihle et al., 2014; Stewart & McFarland, under review). Therefore, we also hypothesized that reported chronic stress at the outset of the study (e.g., perceived chronic stress and PSS scores) would have significant positive correlations with clock monitoring (i.e., both total number of clock checks and the mean number of clock checks within the minute before time-based cue presentation), and in turn, time-based PM performance. In line with the majority of research in the area of chronic stress and event-based PM, we predicted that PCS and PSS scores would have significant negative correlations with both focal/non-focal event-based PM performance.

A possible explanation for the differing directional hypotheses regarding chronic stress and PM type is that because event-based PM may rely more on RM processes of PM (Szőllősi et al., 2018), and chronic stress can impair memory retrieval, then chronic stress might interfere with the necessary processes required for successful event-based PM. Simultaneously, because time-based PM relies more on self-initiated processing, the prospective component of PM, enduring stress might lend to enhanced monitoring behavior for associated time-related cues.

Regarding acute stress, we predicted the existence of significant group differences in PM performance due to acute stress reactions generally, but more specifically, we also predicted that the nature of these relations change as a product of the time of day and the circadian cortisol effect. The rationale behind this prediction is that those tested in the evening might have more optimal levels of stress, and considering that RM processes likely follow an inverted U-shaped dose-response relation with stress levels (Het et al., 2005; Smeets, 2011), we predicted that those tested later in the day would demonstrate an enhanced ability to retrieve PM intentions. Further, optimal levels of arousal can also facilitate the detection of PM cues in one's environment (Sørensen & Barratt, 2014; Sørensen et al., 2014), thus potentially augmenting the ability to identify target cues. To our knowledge, this is the first study to incorporate measurement of acute stress, chronic stress, subjective memory ability, time-based PM, focal and non-focal event-based PM, and time of day.

Method

Participants

Participants were recruited through the psychology pool at the University of Montana (IRB # 219-18). Participants were ineligible for the study if they were under the age of 18, over the age of 40, received a previous or current diagnosis of a neurological condition, had a history of a traumatic brain injury, or received a previous diagnosis of attention-deficit/hyperactivity disorder (ADHD). Students received course credit for their participation. A total of 92 participants completed the study, with a participant mean age of 21.09 years. Of the total sample, 30 identified as male, 61 identified as female, one identified as transgender, and no participants identified as other. In terms of college education, 47 were freshman, 14 were sophomores, 17 were juniors, ten were seniors, three were in their fifth year, and one identified having six or more years of college. The average years of education after high school was 2.03. Regarding ethnicity, 77 identified as Caucasian, three identified as Hispanic/Chicano, two identified as African American, two identified as Native American, three identified as Asian American, four identified as mixed ethnicity, and one identified as other ethnic identity. These sample demographics, apart from age, approximate the Montana State Census (2010) population demographics.

Measurement and Instrumentation

Demographics, Inclusion Criteria, and Perceived Chronic Stress. A standard demographics questionnaire included questions about participant age, biological sex, gender identity, current year in college, and ethnicity/race. Additionally, the questionnaire included questions regarding the exclusion criteria, asking if they were between the ages of 18-40, had a diagnosis of ADHD, any neurological condition, or had experienced an accident in which they became unconscious for over 30 minutes (traumatic brain injury), and if they had received a diagnosis for any other psychological disorder. The questionnaire also included inquiries about perceived chronic stress (PCS), or the self-reported stress levels that participants experienced within the last week (e.g., "On a scale of 0-10, with 0 indicating no stress, and 10 indicating the most stress you have ever experienced, how stressed out have you been over the past week?"). Comparable global measures of perceived chronic stress have demonstrated content, criterion, and construct validity (Cuttler et al., 2019; Elo, Leppänen, & Jahkola, 2003). Perceived stress can predict stress levels more than the number of cumulative life stressors (Clark et al., 2007).

Perceived Stress Scale (PSS). Participants completed the 10-item Perceived Stress Scale (PSS-10; Cohen, Kamarck, & Mermelstein,1983) at the beginning of the study. The PSS is a measure designed to quantify how individuals appraise stressful events in their lives. The items in the scale measure how unpredictable, uncontrollable, or overloaded individuals feel their lives have been over the past month (Lee, 2012). The original instrument included 14 items developed in English, with seven positive and seven negative items rated on a five-point Likert scale (Cohen et al., 1983). Subsequent factor analysis reduced the number of items to ten. The PSS contains qualifiers of levels of stress that are useful for categorizing the amount of stress individuals face. For example, scores ranging from 0-13 have “low stress,” scores ranging from 14-26 have “moderate stress,” and scores ranging from 27-40 have “high stress.” Reliability and validity estimates for the PSS (both the PSS-10 and PSS-14) varied depending on the study, but consistently scored above .70, the minimum number for internal consistency (Nunnally & Bernstein, 1994), as measured by Cronbach’s alpha (Lee, 2012).

Positive And Negative Affect Schedule (PANAS). All participants completed three administrations of the Positive and Negative Affect Schedule (PANAS; Watson, Clark, & Tellegen, 1988), a widely used measure of affective states, to assess momentary subjective stress levels. The Centre for Studies on Human Stress (CSHS) lists the PANAS as a questionnaire used frequently to study environmental and psychosocial stress (Echterhoff & Wolf, 2012; Qin et al., 2009). Administering the PANAS several times throughout the study enabled the measurement of momentary acute stress. PANAS scores, particularly the negative affect (NA) subscale, correlate with GC concentrations (Merz & Roesch, 2011; Polk, Cohen, Doyle, Skoner, & Kirschbaum, 2005). Reliability estimates for the PA and the NA scales were measured using Cronbach’s alpha, with the reliability estimate for PA being .89, and the reliability estimate for NA being .85 (Crawford & Henry, 2004).

Prospective and Retrospective Memory Questionnaire (PRMQ). Participants also completed the Prospective and Retrospective Memory Questionnaire (PRMQ; Smith, Della Sala, Logie, & Maylor, 2000). The PRMQ is a 16-item measure designed to quantify aspects of PM and RM failures in daily life. The instrument devotes half of its items to PM and the other half to RM, with all the items combining to create a general memory index score (Crawford, Henry, Ward, & Blake, 2006). Crawford, Smith, Maylor, Della Sala, and Logie (2003) tested the construct validity of the PRMQ and estimated the internal consistency of the Total, Prospective, and Retrospective scales using Cronbach's alpha. These estimates were .89 for Total scale, .84 for the Prospective scale, and .80 for the Retrospective scale (Crawford et al., 2003).

Time of Day. Participants completed the study in the morning or the evening. The morning time interval was between 8:00 am and noon and the evening time interval was between 3:00 pm and 6:00 pm. Testing in two intervals allowed the analysis of whether testing participants in the morning or evening hours, in conjunction with the circadian rhythm of stress, contributed to any differences in PM performance. We also coded time of day as a continuous variable to identify if the level of PM performance tended to rise or fall depending on the time of day. To accomplish this, we assigned numbers, beginning at 1 and increasing in value, starting at 8:00 am and ending at 6:00 pm. For example, 8:00 am coded as a "1," 8:30 am as a "1.5," 3:00 as an "8," 3:30 as an "8.5," and so on. Comparing the time of day as both continuous and with two categorical groups enabled a comprehensive understanding of how this variable interacts with PM performance, both between and within groups.

Computerized Prospective Memory Task. Participants received instructions for the PM task at the outset of the study to create the PM intention for execution in the future. The PM task was a multiple-choice trivia task (serving as the ongoing task), and participants had 12 seconds to respond to each question. There were both focal and non-focal target words embedded within the trivia, with focal and non-focal cues alternating in presentation after every ten questions.

Both the focal word “animal” and the non-focal target word “can” emerged six times in the trivia questions. The non-focal event-based word “can” appeared only at the beginning of a word (e.g., candidate or canceled). Upon encountering the event-based PM cue, participants needed to press the left shift key on the keyboard. For instance, upon encountering the word “Canada” in a trivia question, the participant then would press the left shift key on the keyboard if successful PM cue recognition took place. This PM task measured both focal and non-focal event-based PM performance. Participants provided a successful event-based PM response when they pressed the left shift key while the trivia question containing the target word remained displayed.

To measure time-based PM, participants were to press the right shift key on the keyboard after a certain time interval elapsed on a digital clock provided on the monitor (e.g., pressing the right shift key after every three minutes since the onset of the task). Successful time-based PM responses depended on whether they pressed the right shift key within a 15-second window of the specific target time (i.e., 15 seconds before or after every three minutes elapsed). Although participants could encounter both event-based and time-based cues simultaneously, the amount of time allowed on each trivia question enabled multiple responses to PM cues, if necessary. For example, pilot testing showed that participants could check the clock, respond to a time-based cue, read and scan the trivia question for an event-based target word, and answer the trivia question within the 12 seconds. The PM task lasted 26 minutes in total, and data collection took place at eight different intervals for the time-based PM task (once every three minutes). Other variables of interest measured included the number of total clock checks, the mean number of clock checks within the minute before time-based cue presentation (i.e., the average number of times participants pressed enter in the minute before a target time in the trivia), ongoing task performance, and average reaction time to trivia questions.

Procedure

Participants first received a detailed description of the study, including the fact that some portions of the study might be uncomfortable. Participants then signed an informed consent form. We randomly assigned participants to either the experimental group or control group by alternating groups as they came into the study. Researchers led the participants to a computer in a private room, where they completed the demographic questionnaire, PSS, and PRMQ through a Qualtrics survey. These measures enabled quantification of chronic stress (e.g., PCS and PSS) and self-reported PM, RM, and general memory ability in daily life. Upon completion of these instruments, participants in both groups received verbal instructions for the PM task that they completed later in the study (forming a PM intention). The instructions were as follows:

"Later in this study, you will complete a trivia task that is designed to test your knowledge. In this trivia task, you will answer a series of multiple-choice trivia questions, and you will have 12 seconds to answer each question. Try to answer them as quickly and accurately as possible. At the same time, we are also interested in your ability to complete two other tasks. For the first additional task, press the "left shift" key when you come across two target words. The first target word is "animal." This word will only appear in the trivia questions and not the answers. The other target word is "can." This word will be harder to find because you will only come across this word in the context of another word. For example, in a trivia question, if you come across the word "candle," you would press the "left shift" key because this word contains the target word "can." This target word will only appear at the beginning of a word, and like the word "animal," will only appear in the trivia questions, not the answers. For the second additional task, press the "right shift" key on the keyboard after every three minutes have elapsed since the start of the task. When you start the task, a timer will keep track of your total time. You may press the “enter” key on the keyboard to display the elapsed time. For example, once three minutes, six minutes, nine minutes, and so on, elapses on the clock, you will press the “right shift” key on the keyboard. Try to press the right shift key as close to the target times as possible. Do you have any questions? These instructions will not be repeated later in the study.”

After providing the instructions for the PM task, researchers asked the participants questions about the task to ensure that they understood the instructions (i.e., a learning check). For example, participants needed to answer questions such as, “when you come across the words ‘animal’ or ‘can,’ what do you do?,” “what do you do after every three minutes have elapsed since the start of the task?,” and “how do you display the timer that shows the elapsed time on the computer?” If a participant answered any of the questions incorrectly, then the researcher repeated the instructions for that portion of the task. The learning check ensured that differences in initial understanding of the task did not contribute to PM performance differences between groups. When participants successfully answered all the questions about the PM task, they completed the PANAS to provide information about their baseline levels of acute stress. They then engaged in their group-specific tasks.

Researchers timed all phases of the TSST (experimental group) and the placebo TSST (control group) with a digital timer to ensure standardization of time for the task across groups. Those in the control group completed a standardized control treatment that matches the cognitive requirements but lacks the stress-inducing features and sense of uncontrollability of the TSST (Het, Rohleder, Schoofs, Kirschbaum, & Wolf, 2009). This placebo TSST entailed asking participants to talk about a recent novel, movie, or a recent trip for five minutes. Participants had a three-minute preparation period during which they could take notes about their chosen topic. After the preparatory period, they talked loudly about their chosen topic in a private room for five minutes. For the placebo mental arithmetic task, participants began at zero and added by intervals of 15 for five minutes. After the allotted time, the researcher asked the participants the number they reached (Het et al., 2009).

Those in the experimental group underwent the original TSST protocol. First, researchers led participants into a room to prepare for the speech portion of the task. Researchers read instructions for the TSST per the script provided by Birkett (2011). The script contains the following instructions for the speech preparation portion of the task: “This is the speech preparation portion of the task; you are to prepare a five-minute speech describing why you would be a good candidate for your ideal job. Your speech will be videotaped and reviewed by a panel of judges trained in public speaking. You have three minutes to prepare and you may take notes. Your time begins now." Participants prepared for the speech in a private room that had a pencil and paper for note taking. After the three-minute preparatory period, researchers then led the participants to a separate room with a spotlight, a video camera, and two confederates with white coats and clipboards. Researchers then read the following instructions for the speech portion: "This is the speech portion of the task. You are to deliver a speech describing why you would be a good candidate for your ideal job. You should speak for the entire five-minutes. Your time begins now." The researcher turned on a prop video camera and a spotlight before participants began their speech. If at any point the participant ceased talking for 20 seconds, the researcher prompted further presentation by saying, “you still have time remaining. Please continue.” Upon completion of the five-minute speech portion, the researcher informed the participant that the speech portion was over.

The final portion of the TSST was the mental arithmetic task. After the speech portion, a researcher read the following script to participants: "During the final five-minute math portion of this task, you will be asked to sequentially subtract the number 13 from 1,022. You will verbally report your answers aloud and be asked to start over from 1,022 if a mistake is made. Your time begins now." The confederates followed the participant's progress via a paper on the clipboard that contained the answers for the arithmetic task, and if the participant provided an incorrect answer, the researcher told the participant, "that is incorrect, please start over from 1,022." The mental arithmetic task lasted for five minutes. The administration of the TSST for the experimental group versus the placebo TSST for the control group constituted the main group differences in treatment for this study. Accordingly, after the conclusion of these different conditions, the procedural description of the study remains identical between those in both the experimental and control group.

Upon completion of the group-specific TSST, a researcher led the participant back to the preparation room with the computer, and participants completed the second PANAS to measure potential changes in acute stress levels. We did not measure salivary GC levels because the TSST paradigm reliably facilitates the induction of GCs (Kelly et al., 2007; Möschl et al., 2017; Nater et al., 2006; Payne et al., 2007; von Dawans et al., 2011; Walser et al., 2013). Using data on the typical time course of stress after stress induction from the TSST, we timed the PM task so that participants completed the task with the maximum levels of acute stress. Salivary cortisol levels tend to peak approximately 10-20 minutes after acute stress induction (Möschl et al., 2017; Nater et al., 2006). Thus, to account for the delayed peak arousal level, we included a ten-minute delay between the TSST and administration of the computerized PM task, during which participants completed a crossword puzzle.

After the ten-minute delay, participants completed the PM task (see the "Computerized Prospective Memory Task" section for more details). The computerized PM task took 26 minutes complete, and after they finished the task, participants again completed the PANAS to demonstrate if stress levels changed before and after the task. Lastly, participants completed a memory check, where they answered the same questions about the PM task as the learning check (i.e., "what were you supposed to do when you encountered the words 'animal' or 'can?'). This helped to determine whether participants remembered the instructions for the task and if there were differences in remembering between groups. Researchers then debriefed participants about the study and provided them with class credit (see Figure 1 for an overview of the procedure).

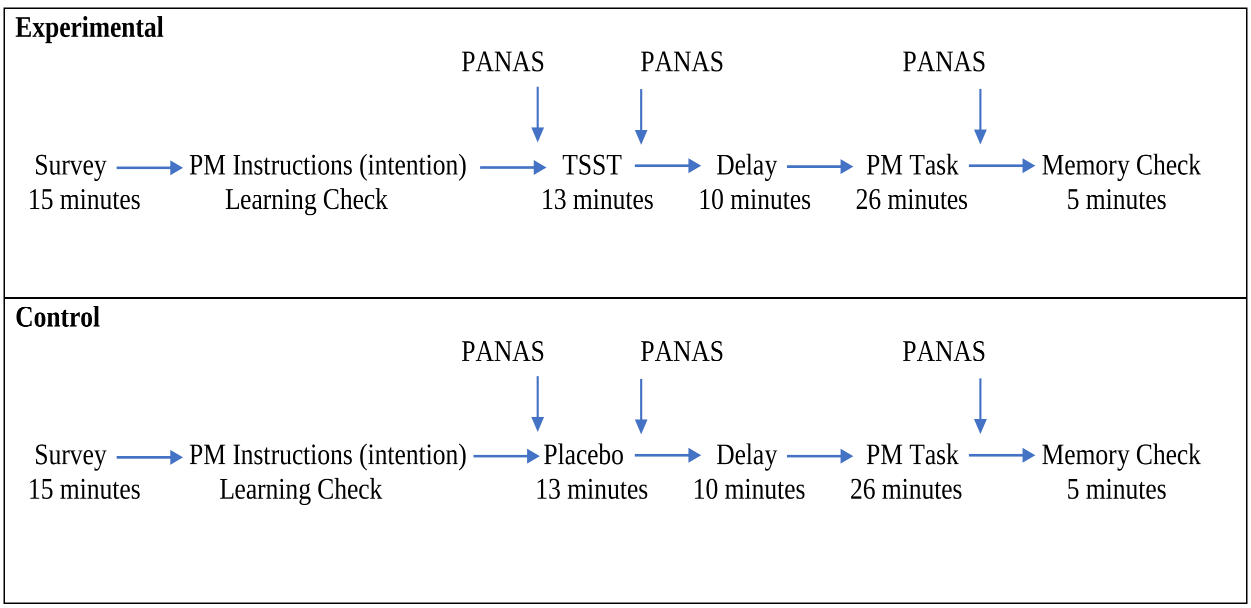

Figure 1. Visual Overview of the Study Procedure

Results

Acute Stress Induction

To investigate the effectiveness of the TSST, a 2x3 Mixed factorial ANOVA with the between-subjects variable of group (experimental vs. control) and the within-subjects variable of PANAS negative affect (NA at time 1, NA at time 2, and NA at time 3) was conducted. The results of the analysis revealed that the TSST stress induction paradigm produced the expected increase in self-reported stress. Specifically, there was a significant main effect of time for NA scores [$F(2, 90) = 9.628$, $p < .001$, $\eta_p^2 = .097$], such that the mean NA scores varied significantly depending on the time of PANAS administration. A significant main effect of group also emerged [$F(1, 90) = 6.202$, $p = .015$, $\eta_p^2 = .064$], revealing that the level of mean NA scores varied as a product of group. Critically, a significant interaction between group and NA scores [$F(2, 90) = 16.293$, $p < .001$, $\eta_p^2 = .153$] also emerged. Post-hoc comparison using the Holm's Sequential Bonferroni Procedure revealed that the mean NA scores of the experimental group ($M = 15.109$, $SD = 4.997$) did not differ significantly from the mean NA scores of the control group ($M = 15.304$, $SD = 4.981$) during the first PANAS assessment at the outset of the study (i.e., time 1), $t(90) = 0.576$, $p = .566$, $d = .060$. Critically, however, post hoc analyses indicated that the mean NA scores of the experimental group ($M = 17.348$, $SD = 6.502$) were significantly higher than the mean NA scores of the control group ($M = 12.500$, $SD = 3.195$) after TSST (original or placebo) treatment (i.e., time 2), $t(90) = 4.160$, $p < .001$, $d = .434$.

Among those in the experimental group, repeated measures ANOVA showed a significant main effect of NA scores for the three times of administration [$F(2, 45) = 11.462$, $p < .001$, $\eta_p^2 = .050$]. Post-hoc comparison using the Holm's Sequential Bonferroni Procedure revealed that the mean NA scores of the experimental group increased significantly from time 1 ($M = 15.109$, $SD = 4.997$) to time 2 ($M = 17.348$, $SD = 6.502$), $t(45) = -2.998$, $p = .009$, $d = -.442$. Repeated measures ANOVAs indicated that there was no such increase among control group participants, but rather a significant decrease in mean NA scores from time 1 ($M = 15.304$, $SD = 4.981$) to time 2 ($M = 12.500$, $SD = 3.195$), $t(45) = 5.209$, $p < .001$, $d = .742$.

Post-hoc analyses also showed that the mean NA scores of the experimental group decreased significantly from time 2 ($M = 17.348$, $SD = 6.502$) to post ($M = 14.326$, $SD = 4.926$)

computerized PM task completion (i.e., time 3), $t(45) = 4.350$, $p < .001$, $d = .641$. Among those in the control group, mean NA scores remained almost equivalent from time 2 ($M = 12.500$, $SD = 3.195$) to time 3 ($M = 12.674$, $SD = 4.033$), $t(45) = -0.378$, $p = .707$, $d = -.056$. The 2x3 Mixed factor ANOVA demonstrated that the mean NA scores for the experimental group ($M = 14.326$, $SD = 4.926$) were numerically higher than the mean NA for the control group ($M = 12.674$, $SD = 4.033$) at time 3. However, the remaining increase was not statistically significant, but rather approached statistical significance, $t(90) = 1.760$, $p = .082$, $d = .367$. The results show that those in the experimental group returned to below baseline acute stress levels at time 3, while those in the control group reported roughly equivalent acute stress levels from time 2 to time 3 (after the initial decrease in mean NA scores) and reported consistently lower levels of acute stress than those in the experimental group (see Figure 2 for a summary of NA scores between groups).

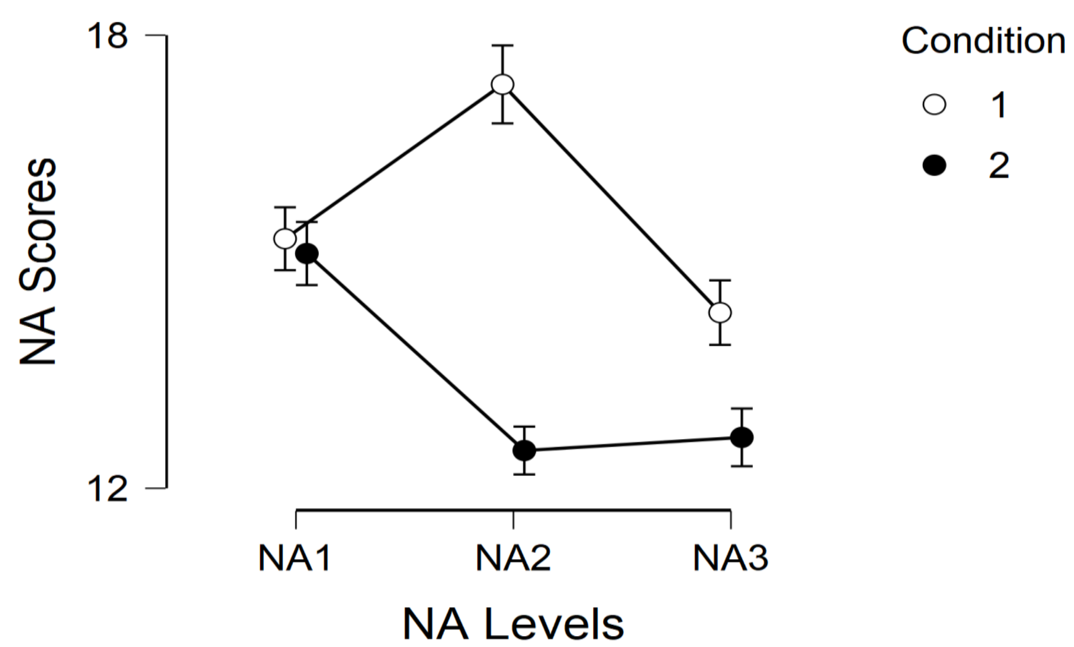

Figure 2. Mean NA Scores in the Condition 1 (Experimental) and Condition 2 (Control)

To assess the impact of the TSST on the positive affect (PA) scale of the PANAS, we conducted a 2x3 Mixed factor ANOVA with the between-subjects variable of group (experimental vs. control) and the within-subjects variable of PANAS positive affect (PA at time 1, PA at time 2, and PA at time 3). The results revealed the expected acute stress levels among both groups. For example, there was a significant main effect of PA scores for the three times of administration [$F(2, 90) = 34.068$, $p < .001$, $\eta_p^2 = .275$] and a significant main effect of group [$F(1, 90) = 5.587$, $p = .020$, $\eta_p^2 = .058$]. The ANOVA also showed a significant interaction between group and PA scores [$F(2, 90) = 4.006$, $p = .008$, $\eta_p^2 = .053$]. Post-hoc comparison using the Holm's Sequential Bonferroni Procedure revealed that the mean PA scores of the experimental group ($M = 25.565$, $SD = 6.853$) did not differ significantly from the mean PA scores of the control group ($M = 27.935$, $SD = 8.185$) at time 1, $t(90) = -1.505$, $p = .136$, $d = -.314$. However, post hoc analyses indicated that the mean PA scores of those in the experimental group ($M = 21.696$, $SD = 7.791$) were significantly lower than the mean PA scores of those the control group ($M = 27.500$, $SD = 8.615$) at time 2, $t(90) = -3.389$, $p < .001$, $d = -.707$.

Post-hoc analyses demonstrated that the mean PA scores of those in the experimental group ($M = 20.478$, $SD = 7.991$) remained numerically lower than the mean PA scores of those the control group ($M = 23.630$, $SD = 9.950$) at time 3. However, the remaining decrease in mean PA scores was not statistically significant, $t(90) = -1.675$, $p = .097$, $d = -.349$. This pattern of mean PA scores is consistent with the mean NA scores across groups, indicating that although a significant decrease of mean PA scores (and increase of mean NA scores) occurred after the original TSST for the experimental group (while the control group maintained similar levels of mean PA scores after the placebo TSST), significant group differences did not remain over the course of the PM task. As expected, Individuals who underwent stress induction procedures also had significant mean reductions in mean PA time 1 (M = 25.565, SD = 6.853) to time 2 (M = 21.696, SD = 7.791), $t(45) = 5.054$, $p < .001$, d = .745. Those in the control group did not report significant elevations or reductions in the PA component of the PANAS from time 1 (M = 27.935, SD = 8.185) to time 2 (M = 27.500, SD = 8.615), $t(45) = .639$, p = .526, d = .094.

Additional post-hoc analyses revealed that those in the experimental group (M = 20.478, SD = 7.991) reported slightly reduced mean PA scores from time 2 (M = 21.696, SD = 7.791) to time 3 (M = 20.478, SD = 7.991), but the reported decrease was not statistically significant, $t(45) = 1.624$, p = .111, d = .239. Analyses of those in the control group showed that there was a statistically significant reduction in mean PA scores from time 2 (M = 27.500, SD = 8.615) to time 3 (M = 23.630, SD = 9.950), $t(45) = 4.044$, $p < .001$, d = .596. It is possible that the time and cognitive demands of the PM task created reductions in mean PA scores for those in the control group (see Figure 3 for a summary of PA scores between groups).

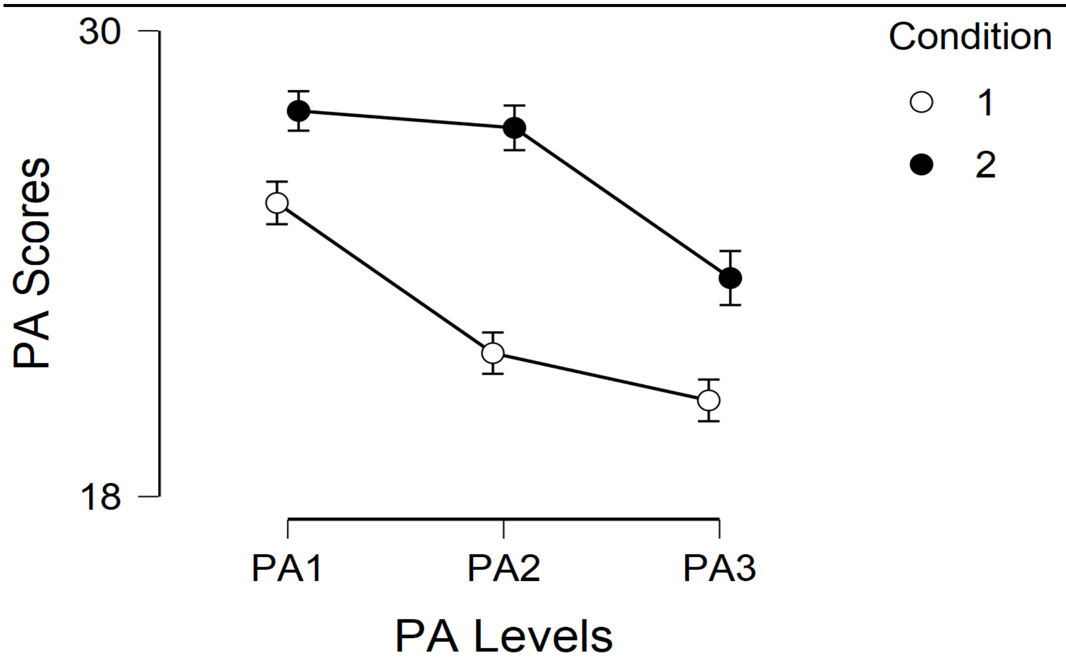

Figure 2. Mean PA Scores in the Condition 1 (Experimental) and Condition 2 (Control)

Prospective Memory Performance

Acute Stress and PM Performance. To investigate the relations between acute stress and PM performance, A 2x3 Mixed factor ANOVA with the between-subjects variable of group (experimental vs. control) and the within-subjects variable of PM type (focal event, non-focal event, and time-based PM) revealed no main effect of group on PM task performance [$F(1, 90) = 0.170$, $p = .674$, $\eta_p^2 = .002$]. Specifically, there were no statistically significant group differences in focal event-based PM, $t(90) = 1.040$, $p = .301$, $d = .217$, non-focal event-based PM, $t(90) = -0.256$, $p = .799$, $d = -.053$, or time-based PM performance, $t(90) = 0.138$, $p = .890$, $d = .029$ (see Table 1 for mean PM task performance between groups). There was also no significant interaction between group and PM type [$F(2, 90) = 0.323$, $p = .724$, $\eta_p^2 = .004$].

Table 1

Prospective Memory Performance Between Groups

PM Type	Condition	Mean	SD	N
Focal EBPM	Experimental	3.239	1.622	46
	Control	2.870	1.784	46
Non-Focal EBPM	Experimental	1.391	1.085	46
	Control	1.457	1.345	46
Time-based PM	Experimental	4.935	3.262	46
	Control	4.848	3.084	46

In line with a lack of general relation between acute stress and PM performance, independent samples *t*-tests revealed that there were no statistically significant group differences in clock monitoring (i.e., the mean number of clock checks), $t(90) = 0.520$, $p = .604$, $d = .108$, strategic clock monitoring (i.e. mean number of clock checks within one minute before time-based cue presentation), $t(90) = 0.522$, $p = .603$, $d = .109$, or mean reaction time to trivia questions, $t(90) = 0.256$, $p = .799$, $d = .053$. There were also no statistically significant group differences in ongoing task performance (e.g., the mean number of correct trivia questions, incorrect trivia questions, and non-responding to trivia questions (t's < 0.799 and p's > .603).

Chronic Stress and PM Performance. As expected, our measures of chronic stress (PCS and PSS) were significantly correlated, $r(90) = .617$, p < .001, suggesting that these measures are both valid assessments of chronic stress levels. Correlational analysis revealed that PCS reported at the outset of the study was significantly correlated with time-based PM performance, $r(90) = -.266$, p = .010, regardless of group. Although PCS was not correlated with total clock checking, $r(90) = -.167$, p = .112, a significant correlation emerged between PCS and strategic clock monitoring, $r(90) = -.258$, p = .013, indicating that higher levels of reported chronic stress were correlated with less strategic clock monitoring. Perceived chronic stress was not significantly correlated with any other PM type. Analyses involving the PSS revealed that the PSS total score was significantly correlated with time-based PM performance, $r(90) = -.214$, p = .040, again regardless of group (see Figure 3). The PSS was also significantly correlated with clock monitoring, $r(90) = -.221$, p = .034, and strategic clock monitoring, $r(90) = -.249$, p = .017. Like the PCS measure, the PSS did not correlate significantly with other PM types (i.e., focal and non-focal event-based PM), r's < .168 and p's > .110. Independent samples t-tests demonstrated statistically significant group differences in both mean PCS scores, $t(172) = 3.065$, $p = .003$, $d = .639$, and PSS total scores, $t(172) = 2.003$, $p = .048$, $d = .418$.

Although there were no significant correlations between acute stress and PM, it is possible that acute stress induced in the study influenced the relations between chronic stress and

PM. To investigate that possibility, we also examined how chronic stress related with PM performance specifically among those in the control group, who did not undergo the stress induction. Among this group, PCS did not correlate significantly with focal event-based PM, $r(45) = -.124$, p = .412, or non-focal event-based PM, $r(45) = -.164$, p = .277, but PCS was significantly correlated with time-based PM, $r(45) = -.343$, p = .020. However, PCS was not significantly correlated with the number of clock checks, $r(45) = -.121$, p = .423, or strategic clock monitoring, $r(45) = -.215$, p = .151, among this group. The PSS had tighter correlations with PM performance. Like the PCS scale, the PSS total was not significantly correlated with focal event-based PM, $r(45) = -.177$, p = .240, or non-focal event-based PM, $r(45) = -.198$, p = .187, but was significantly correlated with time-based PM, $r(45) = -.352$, p = .017, among those in the control group. Like the PCS scale, the PSS was not significantly correlated with the number of total clock checks, $r(45) = -.243$, p = .104, but unlike the PCS scale, the PSS was significantly correlated with strategic clock monitoring, $r(45) = -.307$, p = .038.

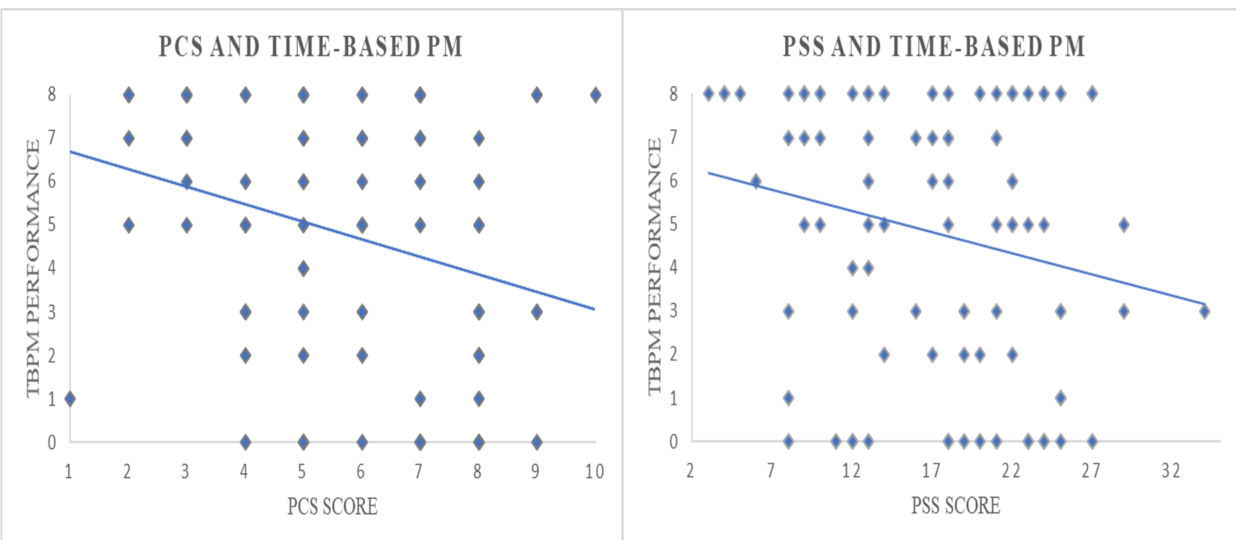

Figure 3. Chronic Stress Measures (PCS and PSS) and Time-Based PM Performance

Comparison of Perceived Chronic Stress: Previous and Current Study. We included identical PCS measures in both the current and our previous (similar) study, thus allowing comparison of chronic stress levels and PM performance between studies. Average PCS levels for the samples in both studies differed, such that those in the previous study reported an average of 5.70 on the scale, and those in the current study reported an average of 6.47. An independent samples *t*-test indicated that the differences in PCS levels between studies were statistically significant, $t(172) = 2.527$, $p = .012$, $d = .383$. This suggests that in general, those who participated in the current study had higher levels of chronic stress than those who participated in the previous study.

Time of Day, Stress, and PM Performance. A 2x3 Mixed factor ANOVA with the between-subjects variable of time of day (morning vs. evening) and the within-subjects variable of PM type (focal event-based PM, non-focal event-based PM, and time-based PM) showed no main effect of time of day on PM task performance [$F(1, 90) = 2.616$, $p = .109$, $\eta_p^2 = .028$,], or a significant interaction between time of day and PM performance, [$F(2, 90) = 1.560$, $p = .213$, $\eta_p^2 = .017$]. When looking at time of day within groups, there were no significant group differences (i.e., morning versus evening) based on time of day for any aspects of PM performance or PM type in the experimental group, *t*'s < .964 and *p*'s > .340, or the control group, *t*'s < 1.275 and *p*'s > .209. With time of day as a continuous variable, it was not significantly correlated with focal event-based PM, $r(90) = .070$, p = .508, non-focal event-based PM, $r(90) = .125$, p = .235, or time-based PM, $r(90) = .153$, p = .145. Time of day was also not significantly correlated with any aspect of PM performance, *r*'s < .110 and *p*'s > .301 (see Table 2 for mean differences in PM performance based on time of day).

Table 2

Prospective Memory Performance Between Morning and Evening Hours

PM Type	TOD	Mean	SD	N
Focal EBPM	Morning	3.13	1.72	46
	Evening	2.98	1.70	46
Non-Focal EBPM	Morning	1.57	1.13	46
	Evening	1.28	1.29	46
Time-Based PM	Morning	5.41	2.86	46
	Evening	4.37	3.38	46

Time of day was not significantly correlated with PCS scale scores, $r(90) = .151$, p = .150, or PSS scores, $r(90) = .032$, p = .761. In parallel, there were no statistically significant group differences in either PCS scale scores, $t(90) = -1.154$, $p = .251$, $d = -.241$, or PSS scores, $t(90) = -0.110$, $p = .913$, $d = -.023$, based on time of day. There were also no significant group differences in reported acute stress levels at the outset of the study as a product of time of day, $t(90) = 0.397$, $p = .692$, $d = .083$. Lastly, time of day did not contribute to significant group differences in self-reported general memory ability, $t(90) = 0.975$, $p = .332$, $d = .203$, RM ability, $t(90) = 1.135$, $p = .260$, $d = .237$, or PM ability, $t(90) = 0.705$, $p = .483$, $d = .147$.

Stress, Self-Reported Memory Abilities, and Prospective Memory Performance. Both the PCS and the PSS were significantly correlated with reported acute stress at the outset of the study (before stress induction). The PSS scale had tighter correlations with NA scale scores, $r(90) = .451$, p < .001, than PCS, $r(90) = .205$, p = .049. The PSS total was also significantly correlated with experimental group NA scale scores at the outset of the study, $r(45) = .365$, p = .013, and especially with those in the control group, $r(45) = .535$, p < .001. The PCS measure was significantly correlated with control group NA scores, $r(45) = .404$, p = .005, but did not correlate significantly with experimental group NA scores at time 1, $r(45) = .006$, p = .969.

There were no significant group differences in PRMQ total scores (general memory), $t(90) = -1.603$, $p = .113$, $d = -.334$, PM scale scores, $t(90) = -1.700$, $p = .093$, $d = -.354$, or RM scale scores, $t(90) = -1.292$, $p = .200$, $d = -.269$. However, measures of acute and chronic stress were significantly correlated with self-reported memory abilities. For example, PSS total scores were significantly correlated with PRMQ total, or one's self-reported RM and PM abilities, $r(90) = -.529$, p < .001. Concurrently, the PSS was also significantly correlated with the PM scale of the PRMQ, $r(90) = -.551$, p < .001, as well as the RM scale, $r(90) = -.437$, p < .001. The PCS measures were also significantly correlated with PRMQ total scores, $r(90) = -.308$, p = .003, and in turn, PM scale scores, $r(90) = -.328$, p < .001, and RM scale scores, $r(90) = -.247$, p = .017. Acute stress reported at the outset of the study was significantly correlated with PRMQ total scores, $r(90) = -.425$, p < .001, PM scale scores, $r(90) = -.392$, p < .001, and RM scale scores, $r(90) = -.405$, p < .001. These correlations suggest that there are negative relations between one's reported acute and chronic stress levels and perception of one's memory abilities. However, the picture becomes clearer when including objective relations between stress and PM performance.

Total PRMQ scores were not significantly correlated with focal event-based PM performance, $r(90) = .094$, p = .370, or non-focal event-based PM performance, $r(90) = .048$, p = .650, but general memory scores have a significant correlation with time-based PM performance, $r(90) = .206$, p = .048, regardless of group. The RM scale was also significantly correlated with focal event-based PM, $r(90) = .094$, p = .374, non-focal event-based PM, $r(90) = .006$, p = .952, and time-based PM, $r(90) = .236$, p = .024. Importantly, self-reported PM scale scores did not have significant correlations with any PM type, including focal event-based PM, $r(90) = .084$, p

= .327, non-focal event-based PM, *r*(90) = .094, p = .375, or time-based PM, *r*(90) = .154, p = .143. Consistent with the relations between general memory abilities and time-based PM, PRMQ total scores were significantly correlated with strategic clock monitoring, *r*(90) = .220, p = .035. The RM scale was also significantly correlated with this variable, *r*(90) = .235, p = .024, while its correlation with PM scale scores only approached statistical significance, *r*(90) = .180, p = .086. The PM scale did not correlate significantly with other variables related to PM performance, *r*'s < .172 and *p*'s > .101.

Recall of Task Instructions. We also included a memory check after the computerized PM task to identify if there were any significant group differences in the ability to recall the instructions of the task, possibly attributable to induction of acute stress before intention recall and execution. Independent samples *t*-tests demonstrated that there were statistically significant group differences in instruction recall between the experimental and control group, *t*(90) = 2.046, *p* = .044, *d* = .427, such that those in the control group remembered the PM task instructions at a higher rate than those in the experimental group. However, self-reported acute stress levels among those in the experimental group, after stress induction (time 2), were not significantly correlated with instruction recall rate, *r*(45) = .190, p = .206. Self-reported acute stress levels at time 1 also did correlate significantly with instruction recall rate, *r*(90) = .133, p = .207. Perceived chronic stress was significantly correlated with instruction recall rate, *r*(90) = -.208, p = .046, regardless of group, but the PSS scale did not demonstrate this same significant correlation, *r*(90) = -.125, p = .236. Task instruction recall was significantly correlated with focal event-based PM, *r*(90) = .374, p < .001, non-focal event-based PM, *r*(90) = .250, p = .016, time-based PM, *r*(90) = .276, p = .008, and strategic clock monitoring, *r*(90) = .214, p = .040.

PM Performance and Other Variables of Interest. We also analyzed other variables of interest, such as participant sex, age, and relations between other aspects of PM to identify if they contributed to PM performance. There were no significant group differences in PM performance based on participant sex, including focal event-based PM, non-focal event-based PM performance, and time-based PM performance, t's < 1.371 and p's > .174. Participant sex also did not contribute to significant differences in the total number of clock checks, strategic clock monitoring, ongoing task performance, or mean reaction time to trivia questions, t's < .118 and p's > .892. Participant age also was not significantly correlated with the aforementioned variables, r's < .122 and p's > .266. As anticipated, the total number of clock checks was significantly correlated with time-based PM performance, $r(90) = .533$, $p < .001$. Strategic clock monitoring also correlated significantly with time-based PM performance, $r(90) = .633$, $p < .001$.

Discussion

Given the importance and prevalence of PM tasks in daily life, and the common experience of stress, it is critical to further our understanding of their relations. Despite a growing literature base, several key questions remain unanswered. Therefore, we sought to contribute to the literature by investigating the relations between acute stress, chronic stress, and focal, non-focal, and time-based PM. The results of the present study did not reveal the anticipated relation between acute stress and PM in focal, non-focal, or time-based tasks. The lack of relations remained despite a successful acute stress induction among those in the experimental group. Specifically, the TSST stress induction procedure led to increases in acute stress levels (i.e., significant elevations of mean NA scores and significant decreases in mean PA scores). Thus, the results of the study were contrary to our hypothesis that acute stress would positively impact PM performance. Similar to the absence of significant relations between acute stress and PM, acute stress was not related to monitoring behavior (e.g., clock checking, strategic clock checking, and ongoing task performance). The lack of significant group differences in these aspects of PM performance is not surprising given the lack of significant group differences in the three types of PM tasks included in the study. Additionally, the absence of group differences in ongoing task performance suggests that the lack of PM differences was not the product of different allocations of attentional resources between groups.

In contrast to our findings regarding acute stress and PM, the results of the present study revealed that chronic stress correlated negatively with time-based PM performance as well as other key variables that contribute to successful PM performance, such as the total number of clock checks and strategic clock monitoring. This pattern of results suggests that chronic stress exerted negative effects on time-based PM performance via reduced overall and strategic clock monitoring. This is likely due to the fact that time-based PM requires more self-initiated processing, and thus, chronic stress may have interfered with the prospective processes necessary for successful time-based PM execution. These results diverge from those of our previous unpublished study, in which chronic stress was significantly and positively correlated with clock monitoring and time-based PM. One explanation that can incorporate the opposing results between the two studies pertains to the level of chronic stress reported in both studies. For example, the mean PCS score in the previous study was 5.70, compared to 6.47 in the present study. Thus, in our previous study, participants reported chronic stress that may have fallen within an optimal range, leading to the enhancement of monitoring and time-based PM. In contrast, the higher reported chronic stress in the present study was negatively correlated with clock monitoring and time-based PM. Therefore, it is possible that the relations between chronic stress and time-based PM follows the inverted U dose-response curve, and in the present study, participants may have experienced excess levels of chronic stress that contributed to decrements in monitoring and in turn, the ability to complete time-based intentions.

We also investigated the potential influence of time of day in this study, with the aim of clarifying the disparate findings in the acute stress and PM literature. Contrary to our predictions, no significant correlations emerged between time of day and PM performance, whether broadly across groups, or in particular, among those in the experimental group who underwent stress induction. The same pattern held with time of day treated as a continuous variable. Time of day also did not correlate significantly with chronic stress levels or self-reported general memory abilities, including both RM and PM. Although this was the first study in the stress-PM literature to incorporate time of day as an explicit variable in relation to stress induction, it did not hold much significance when attempting to disentangle the relations between various forms of stress and PM types. Even with the addition of acute stress induction alongside varying basal levels, the non-significant relation with PM performance remained.

Results of analyses of subjective memory revealed that stress levels were significantly correlated with self-reported memory abilities, suggesting that stress levels could influence one's perception of memory ability. Measures of both acute and chronic stress were negatively correlated with self-reported memory abilities, including both PM and RM, while self-reported general memory abilities were positively correlated with time-based PM performance, but not with focal or non-focal event-based PM. Although the exact temporality of these relations is unclear, it appears that those with higher levels of stress in general are more likely to report subjective memory complaints, and those with subjective memory complaints are more likely to do poorly on time-based PM tasks. Of course, due to the correlational nature of these relations, future research is required to identify the time course along which these variables may interact.

One somewhat surprising finding was the lack of relations between PRMQ PM scale scores and PM performance. This suggests that the participants' subjective PM abilities did not reflect their objective PM performance. This is not the first study to reveal subjective PM ability to be inaccurate (e.g., Chan et al., 2008). Nevertheless, because successful PM relies on both prospective and retrospective components, using the general memory ability scale might more precisely reflect the necessary mechanisms for PM performance, as the general memory index (including the RM scale) was significantly correlated with time-based PM performance.

Limitations

There were several limitations to the present study. The first limitation related to the PM task. The inclusion of three PM tasks embedded within an ongoing task likely made the task difficult. The non-focal task proved especially challenging for both groups of participants, perhaps reducing the sensitivity of the task and thus our ability to identify differences that may exist. Simultaneously, we hoped to include a task of sufficient difficulty to place greater demands on the self-initiated processing that stress influences, thereby allowing observation of the relations between acute stress and PM. Another potential limitation surrounded the use of self-report measures to quantify levels of acute stress. For example, Glienke and Piefke (2017) found that subjective stress levels did not necessarily reflect physiological reactions to stressors. It is plausible that the use of only subjective measures contributed to the limited relations between acute stress and our variables of interest. On the other hand, the subjective measures of acute stress followed the predicted patterns of stress reactivity through stress induction procedures. Additionally, we timed the PM task to correspond with the time course of cortisol through TSST procedures based on previous research (e.g., Nater et al., 2006), and still found no statistically significant group differences in PM performance.

Another potential limitation of this study, and to the field at large, regards the relation between perceived acute and chronic stress. Given the possibility that one's chronic stress levels affected report of acute stress levels, and because participants reported on both types of stress at similar points in time, future research might quantify biological variables related to stress (e.g., HCC versus salivary GC versus subjective stress levels) to clarify the relations between acute stress, chronic stress, and PM. Thirdly, we did not assess for the use of contraceptives or other hormone-modifying substances, both of which are variables that modify the interaction between stress and memory (Shield et al., 2017). Lastly, this study focused on a healthy college sample, possibly limiting the generalizability of the results, despite the sample approximating the characteristics of the population of Montana according to the Montana State Census (2010).

Summary and Future Directions

The present study contributes to the growing body of literature on stress and PM by revealing that chronic stress can have harmful relations with subjective memory ability, clock monitoring and strategic clock vigilance, as well as time-based PM performance. Thus, those in high-stress environments (e.g., college students) may be at increased risk of failing to execute time-based intentions. These findings contrast with those of acute stress, such that acute stress did not result in group differences in variables related to PM or PM performance. Prospective memory performance was not related to time of day, nor did time of day, in conjunction with stress induction, contribute to significant group differences in PM performance. Future research can examine the notion that acute stress induction prior to intention formation and execution, and during particular times of the day, could enhanced PM performance.

Research in the area of stress and PM is beginning to identify their relations. Future work in this area could begin to examine more in-depth the impact of chronic stress on time-based PM, as many studies in the area neglect their assessment and investigation of their relations. In this study and our previous study, chronic stress connected only with time-based PM performance. Although we found initial evidence within the current study and our previous study that chronic stress and time-based PM follow an inverted U dose-response curve, this notion warrants further research for confirmation of this relational pattern. Contrary to the growing evidence of negative relations between chronic stress and event-based PM, we did not find a significant association between chronic stress or either type of event-based PM. Another topic of interest surrounds the relations between stress, self-reported PM performance, and objective PM performance (including the temporality of their relations). Continuing to explore the nuanced ways in which stress and PM interact will clarify whether different types of stress can be beneficial or detrimental to one's ability to complete intentions in the future, and under what conditions.

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Appendix

Perceived Stress Scale (PSS)

The questions in this scale ask you about your feelings and thoughts during the last month. In each case, you will be asked to indicate by circling how often you felt or thought a certain way.

Name ____ Date _______________

Age ________ Gender (Circle): M F Other ____

0 = Never 1 = Almost Never 2 = Sometimes 3 = Fairly Often 4 = Very Often

1. In the last month, how often have you been upset because of something that happened unexpectedly? 0 1 2 3 4
2. In the last month, how often have you felt that you were unable to control the important things in your life? 0 1 2 3 4
3. In the last month, how often have you felt nervous and "stressed"? 0 1 2 3 4
4. In the last month, how often have you felt confident about your ability to handle your personal problems? 0 1 2 3 4
5. In the last month, how often have you felt that things were going your way? 0 1 2 3 4
6. In the last month, how often have you found that you could not cope with all the things that you had to do? 0 1 2 3 4
7. In the last month, how often have you been able to control irritations in your life? 0 1 2 3 4
8. In the last month, how often have you felt that you were on top of things? 0 1 2 3 4
9. In the last month, how often have you been angered because of things that were outside of your control? 0 1 2 3 4
10. In the last month, how often have you felt difficulties were piling up so high that you could not overcome them? 0 1 2 3 4

Positive And Negative Affect Schedule (PANAS) Questionnaire

This scale consists of a number of words that describe different feelings and emotions. Read each item and then list the number from the scale below next to each word. Indicate to what extent you feel this way right now, that is, at the present moment OR indicate the extent you have felt this way over the past week (circle the instructions you followed when taking this measure)

1	2	3	4	5
Very Slightly	A Little	Moderately	Quite a Bit	Extremely

___________ 1. Interested	___________ 11. Irritable
___________ 2. Distressed	___________ 12. Alert
___________ 3. Excited	___________ 13. Ashamed
___________ 4. Upset	___________ 14. Inspired
___________ 5. Strong	___________ 15. Nervous
___________ 6. Guilty	___________ 16. Determined
___________ 7. Scared	___________ 17. Attentive
___________ 8. Hostile	___________ 18. Jittery
___________ 9. Enthusiastic	___________ 19. Active
___________ 10. Proud	___________ 20. Afraid

Scoring Instructions: Positive Affect Score: Add the scores on items 1, 3, 5, 9, 10, 12, 14, 16, 17, and 19. Scores can range from 10 – 50, with higher scores representing higher levels of positive affect. Mean Scores: Momentary 29.7 (SD 7.9); Weekly 33.3 (SD 7.2) Negative Affect Score: Add the scores on items 2, 4, 6, 7, 8, 11, 13, 15, 18, and 20. Scores can range from 10 – 50, with lower scores representing lower levels of negative affect. Mean Score: Momentary 14.8 (SD 5.4); Weekly 17.4 (SD 6.2).

Prospective and Retrospective Memory Questionnaire (PRMQ)

Do you decide to do something in a few minutes' time and then forget to do it?

- Very often
- Quite often
- Sometimes
- Rarely
- Never

Do you fail to recognize a place you have visited before?

- Very often
- Quite often
- Sometimes
- Rarely
- Never

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?

- Very often
- Quite often
- Sometimes
- Rarely
- Never

Do you forget something that you were told a few minutes before?

- Very often
- Quite often
- Sometimes
- Rarely
- Never

Do you forget appointments if you are not prompted by someone else or by a reminder such as a calendar or diary?

- Very often
- Quite often
- Sometimes
- Rarely
- Never

Do you fail to recognize a character in a radio or television show from scene to scene?

- Very often
- Quite often
- Sometimes
- Rarely
- Never

Do you forget to buy something you planned to buy, like a birthday card, even when you see the shop?

- Very often
- Quite often
- Sometimes
- Rarely
- Never

Do you fail to recall things that have happened to you in the last few days?

- Very often
- Quite often
- Sometimes
- Rarely
- Never

Do you repeat the same story to the same person on different occasions?

- Very often
- Quite often
- Sometimes
- Rarely
- Never

Do you intend to take something with you, before leaving the room or going out, but minutes later leave it behind, even though it's there in front of you?

- Very often
- Quite often
- Sometimes
- Rarely
- Never

Do you mislay something that you just put down, like a magazine or glasses?

- Very often
- Quite often
- Sometimes
- Rarely
- Never

Do you fail to mention or give something to a visitor you were asked to pass on?

- Very often
- Quite often
- Sometimes
- Rarely
- Never

Do you look at something without realizing you had seen it moments before?

- Very often
- Quite often
- Sometimes
- Rarely
- Never

If you tried to contact a friend or relative who was out, would you forget to try again later?

- Very often
- Quite often
- Sometimes
- Rarely
- Never

Do you forget what you watched on television the previous day?

- Very often
- Quite often
- Sometimes
- Rarely
- Never

Do you forget to mention to tell something to someone you had meant to mention a few minutes ago?

- Very often
- Quite often
- Sometimes
- Rarely
- Never