Acute Psychosocial Stress and Prospective Memory:

The mediating effect of working memory

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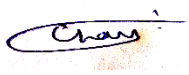
SIGNATURE: 

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Abstract

Background and Aims: Prospective memory (PM) is the ability to execute a previously encoded intention in the future. As such, intact PM is crucial for everyday functioning. Acute psychosocial stress is also present in our everyday life, and also has crucial effects of our everyday functioning. Working Memory (WM) can be defined as a limited capacity cognitive system that allows temporary storage and manipulation of environmentally salient information. As per this definition, we can see that WM is also a very important construct that we use for everyday functioning. Given the importance of these constructs, it is surprising to see that few studies have focused on the effects of stress on PM. While there are a few studies which focused on the effect of WM on PM performance, none of them included stress as a variable. This research aimed at expanding the literature by studying the effects of stress on PM performance at different phases of PM processing, for both time-based and event-based PM tasks, both in the laboratory and naturalistically. Furthermore, it also brought all three constructs together so as to examine whether working memory mediates the relationship between stress and PM and add novel information to the literature.

Methods: Participants were randomly assigned to one of 4 experimental Groups; two stress groups and two control groups, and were tested individually on 2 consecutive days. The Fear Factor Stress Test (FFST) was used as the stress inducing tool for the stress groups. The FFST was either administered before encoding or 24-hours later, just before retrieval. WM was measured just before the FFST on the first day of testing. On the second day of testing, event-based and time-based tasks were administered to participants.

Results: Our results show that PM is rather robust to the effects of stress. However, this study did find that stress affects performance on naturalistic time-based PM tasks. It also found that time-based PM performance is better than performance on event-based PM tasks in real-life settings across all conditions. A surprising result was that no statistically significant difference in PM performance was found whether stress was induced at encoding or retrieval.

Conclusion: Our findings provide valuable information about the performance of time-based and event-based PM tasks in real-life. However, it did not find any statistically significant difference in PM performance when stress is induced at either encoding or retrieval. This is surprising given the research done on the area of stress and memory and therefore calls for further investigation.

Acute Psychosocial Stress and Prospective Memory:

The mediating effect of working memory

Prospective memory (PM) is "memory for activities to be performed in the future" (Einstein & McDaniel, 1990, p. 717). For instance, remembering to eat at a future-specified time is a PM task. PM is important for daily functioning as it gives people the ability to perform intended actions in the future (e.g., taking medication at lunchtime) without having to engage in verbal rehearsal (Burgess, Quayle, & Frith, 2001; Schnitzpahn, Stahl, Zeintl, Kaller, & Kliegel, 2013). Because PM is so important in ensuring optimal daily functioning, psychologists strive to understand factors that affect its successful performance.

Numerous studies in the psychological literature suggest that working memory (WM) capacity, or the degree to which cognitive resources are expended on WM tasks while engaged in PM tasks, affects PM performance (see, e.g., Marsh & Hicks, 1998; Smith & Bayen, 2004). Some studies have also researched the effect of psychosocial stress on PM (see, e.g., Nakayama, Takahasi, & Radford, 2005; Nater, Okere, Stallkamp, Moor, Ehlert, & Kliegel, 2006; Walser et al., 2013). However, no published study has investigated possible mediating effects of WM capacity on the relationship between psychosocial stress and PM. Investigation of such effects is important because it will provide a better understanding of, for instance, why there are individual differences in the effects on PM performance of psychosocial stress.

Prospective Memory: A definition

PM comprises retrospective and prospective memory components (Einstein & McDaniel, 1996). The retrospective memory component involves remembering the content of the PM task (i.e., it involves encoding instructions for what is to be done, and then storing that information until the appropriate time or context arrives). The prospective memory component involves remembering to perform the intended action at a specific time or when the appropriate cue presents itself. This is an automatic process (Einstein, Holland, McDaniel, & Guynn, 1992). For instance, the retrospective component of a PM task might involve taking a telephone message, then remembering the message's content until it can be delivered. The prospective component of that task would be to recognize the person to whom the message should be delivered, and to have the appearance of that individual trigger memory for the message and its contents.

An alternative way to describe the realization of a PM task is the four-stage process model (Kliegel, Eschen, & Thone-Otto, 2004). *Intention formation* involves creating a plan of

what action is to be performed, at what time, or in which context. *Intention retention* involves retaining the intention while performing an ongoing task. *Intention re-instantiation* involves retrieving the intended action from memory while inhibiting ongoing tasks. *Intention execution* involves executing the intended action.

There are two types of PM tasks. *Time-based* tasks require individuals to perform intended actions after a certain period of time has elapsed, or at a specific time. *Event-based* tasks require individuals to perform intended actions when they encounter a specific and externally presented cue (Kliegel & Jager, 2006). Event-based tasks require fewer executive resources than time-based tasks (Williams, Jarrold, Grainger, & Lind, 2014).

Regardless of whether the task is characterized as time-based or event-based, all PM tasks contain three core features. First, there must be a delay between the encoding of the task instructions and the execution of those instructions. Second, the delay interval must be filled with an ongoing task, or a set of ongoing tasks, unrelated to the PM instruction. This task, or set of tasks, serves to prevent rehearsal of the PM task instructions. Third, the execution of the PM task should be self-initiated; there should not be an explicit reminder to perform the PM task when a particular event occurs, when a particular time is reached, or when a particular context is encountered (Burgess et al., 2001).

Working Memory: A definition

The construct of WM refers to a limited capacity cognitive system that allows temporary storage and manipulation of environmentally salient information. WM supports higher-order human thought processes (e.g., learning, decision-making, and problem-solving; Baddeley, 1992, 2003). Baddeley (1992) proposed a WM model comprising three components: a central executive and two slave systems, the phonological loop and the visuospatial sketchpad.

Within Baddeley's model, the central executive controls the two slave systems, and coordinates information flowing to and between them. The phonological loop is the temporary storage centre and processing system for sound and language information. One of its primary functions is to facilitate language acquisition. The visuospatial sketchpad is the temporary storage centre and processing system for visual and spatial information. One of its primary functions is to facilitate spatial orientation (Baddeley & Hitch, 1994).

Effects of Working Memory on Prospective Memory

A consensus has emerged in the literature that, if the ongoing task has a high WM load, event-based PM performance will be affected negatively (see, e.g., Kidder, Park, Hertzog, Morrell, 1997; Marsh & Hicks, 1998; Marsh, Hicks & Cook, 2005; Smith, 2003;

Stone, Dismukes & Remington, 2001). For instance, Stone et al. (2001) studied the effects on PM performance of WM load within a visual-spatial task. This ongoing task consisted of directing airplanes across different waypoints on a screen. The PM task consisted of diverting a specific plane to a different waypoint than its routine one, after either 1, 3, or 5 minutes of the ongoing task. Phonological rehearsal was blocked by making the participants repeat aloud an auditory messaged played to them through headphones. The researchers varied the WM load by varying the number of planes on the screen: Low load was 3 airplanes on the screen, and high load was 7 or 8 airplanes. They found that PM errors increased with WM load, but only when phonological rehearsal was blocked. There was no increase in PM errors when the delay increased from 1 to 5 mins (Stone et al., 2001).

Taking a different approach to demonstrating the relationship between WM and PM, Richter, Modden, Eling, and Hildebrandt (2015) showed that improvement in WM capacity as a result of a WM training intervention was associated with improved PM performance. The study included 44 patients from a rehabilitation centre. Each had a brain lesion that occurred at least 60 days prior to the study and that did not cause severe cognitive impairment. The sample was homogenous in terms of age, education, rehabilitation time, and time since brain lesion. The intervention took place over nine 30-min sessions, and consisted of a card game exercise on computer-based software known to enhance WM capacity, a word fluency exercise, and a semantic structuring exercise. After the therapeutic intervention, the composite score for WM increased from an average of 28.9 ± 8.6 to 36.6 ± 7.1, and the composite score for PM increased from 6.9 ± 2.0 to 9.1 ± 1.5.

The Preparatory Attentional Process and Memory Process (PAM) theory of PM (Smith, 2003; Smith & Bayen, 2004, 2005) attempts to account for the relationship described in the studies reviewed above. Specifically, the PAM theory proposes that successful PM performance is dependent on capacity-consuming preparatory processes that draw upon WM capacity. One example of such a preparatory process is the monitoring of the environment for the cue that will elicit event-based PM performance. Within this theory, whether and how much one can engage in this preparatory process is dependent on WM resource availability (i.e., how much the demands of the ongoing task consume WM resources). Hence, the PAM theory predicts that when the ongoing task is demanding, PM performance will decline. The theory also predicts that when WM training improves the capacity/efficiency of that cognitive system, PM performance will improve.

Stress and Prospective Memory

A large body of literature examines the effects of stress on retrospective memory (RM; see, e.g., McEwen & Sapolsky, 1995; Buchanan & Lovallo, 2001). Findings within this literature suggest that exposure to either physiological or psychosocial stress can either strengthen or weaken memory performance, depending on the memory type and the phase of processing under investigation (Cornelisse, Van Stegeren, & Joels, 2011). For instance, Roozendaal (2002) noted that an increase in glucocorticoids (adrenal hormones (in humans: cortisol) released in response to the experience of stressful events) enhances consolidation of new information while impairing retrieval of previously stored information.

Given that glucocorticoids bind extensively with receptor sites in the prefrontal cortex (PFC) after their stress-induced release (Arnsten, 2009), and that PM performance is also related to PFC activity (Walser, Fischer, Goschke, Kirschbaum, & Plessow, 2013), it seems important to investigate the effects of stress on PM performance. However, only three studies have investigated those effects.

Nakayama and colleagues (2005) examined the effects of chronically elevated cortisol on both RM and PM performance in male participants. They reported a strong positive correlation between cortisol levels and RM performance, but no significant correlation between cortisol levels and PM performance. Subsequently, Nater and colleagues (2006) examined the effects of acute cortisol elevations (induced by exposure to a psychosocial stressor) on both time-based and event-based PM in a group of male participants. They reported no significant relationship between cortisol elevation and event-based PM performance, but enhanced time-based PM performance following stress exposure. Recently, Walser and colleagues (2013) extended the research by examining the stress-PM relationship in a sample containing both men and women. They reported no significant relationship, in either men or women, between exposure to an acute psychosocial stressor and event-based PM performance.

Rationale and Significance

The review above shows there is scant research investigating the effects of psychosocial stress on PM performance. Given the neurophysiological link between stress and PM, additional research on their relationship is warranted, particularly given the inconsistent results reported by the extant studies. The importance of studying potential effects of stress on PM performance is made even clearer when one considers that many individuals across many walks of life experience stress frequently in their daily lives, and that, for most people, intact PM is crucial for ensuring optimal daily functioning. This study contributes to the stress-PM

literature by examining the effects of stress at different phases of PM processing (encoding/retention versus retrieval/execution) on both time-based and event-based PM tasks. No previous study has undertaken such an examination.

The present study also takes a step further by examining the mediating effect that WM capacity has on the relationship between exposure to acute psychosocial stress and PM performance. No previous study has examined that mediating effect. If the study detects a significant mediating effect, researchers, clinicians, and educators will benefit from the knowledge that WM-based interventions might enhance PM performance in everyday situations or jobs (e.g., that of an air traffic controller) where stress exposure is expected and uncontrollable (Richter et al., 2015).

Finally, one major limitation in the literature on the relationship between WM and PM is that most research has been conducted on the effects of WM capacity on event-based PM performance (see, e.g., Marsh, Hicks, & Cook, 2005; Smith, 2003). Only two studies (Mackinlay et al., 2009; Voigt et al., 2014) have examined the relationship between WM capacity and time-based PM performance, but both of those studies focused on children. The present study contributed new information to the literature by studying the effects of WM capacity on time-based PM performance in adults. This addition is important because WM abilities are still developing in childhood, and only mature around the age of 19 years (Luna et al., 2004). Hence, one might argue that the WM-PM relationship is best studied in adults as their abilities in both of these cognitive domains are more likely to be fully developed and stable.

Aims and Hypotheses

The present study aimed to investigate (a) the effects of acute psychosocial stress across different phases of PM processing (i.e., encoding/retention and retrieval/execution), for both time-based and event-based PM tasks, and (b) the effect of WM memory capacity on time-based PM performance (c) possible mediating effects of WM capacity on the relationship between acute stress and PM. Hence, the study tested the following hypotheses:

1) Under conditions of acute stress, participants will have poorer time- and event-based PM performance than under normal conditions;
2) When acute stress is induced at encoding, PM performance will be poorer than when acute stress is induced at retrieval;
3) Under all conditions, participants' performance on time-based PM tasks will be poorer than on event-based tasks;

4) Under all conditions, time-based PM performance will increase when WM capacity increases.
5) WM capacity, as measured by performance on an *n*-back task, will mediate the effects of stress on both time- and event-based PM performance.

Methods

Design and Setting

This study used a 2x2x2 factorial quasi-experimental design. Independent variables were: participants' psychological state (stressed vs. relaxed); stage of memory process at which stress was induced (encoding/retention vs. retrieval/execution); and type of PM task (time-based vs. event-based). Outcome variables were participants' performance on PM tasks (i.e., accuracy for naturalistic and laboratory time-based, speed and error rate for laboratory event-based, and accuracy for Naturalistic event-based PM) (Barnes & Lewis, 2015). The mediating variable was the participants' accuracy on the three-back WM task.

Each participant was assigned randomly to one of four experimental groups (n = 16 for groups SEDR, CEDR, EDSR, and n = 15 for group EDCR; see Table 1). Each then attended two test sessions, one per day on 2 consecutive days. There was a 24-hour delay between the two sessions so as to allow for information encoded in the first session to consolidate in the participant's memory. Test sessions started in the late afternoon/evening (at either 16h00 or 18h00), to control for diurnal cortisol rhythms (Kudielka, Hellhammer, & Wüst, 2009; Barnes & Lewis, 2015).

Table 1.
Outline of Procedures for Each Group in the Experiment (N=63)

Group Name	Procedure Order				Stage of Memory Process Under Investigation
	Stage 1	Stage 2	Stage 3	Stage 4	
SEDR	Stress	Encoding	24-hour delay	Retrieval	Encoding / Retention
CEDR	Control	Encoding	24-hour delay	Retrieval	–
EDSR	Encoding	24-hour delay	Stress	Retrieval	Retrieval / Execution
EDCR	Encoding	24-hour delay	Control	Retrieval	–

Note. SEDR = Stress-Encode-Delay-Retrieve; CEDR = Control-Encode-Delay-Retrieve; EDSR = Encode-Delay-Stress-Retrieve; EDCR = Encode-Delay-Stress-Retrieve.

Participants

Sample. I recruited 112 male undergraduate students, aged 18-30 years, using convenience sampling (i.e., the UCT Department of Psychology's Student Research

Participation Program (SRPP)). However, due to high attrition rate (n = 49; see Figure 1), the final sample size was 63. Regarding statistical power, this sample size yields, with a predicted moderate effect size of d = .40 and with p set at .05, a value for (1 - β) = .73 (Faul, Erdfelder, Buchner, & Lang, 2009).

Exclusion criteria. Women were excluded from participation because, typically, they are less responsive to acute psychosocial stressors in the laboratory environment (Kirschbaum, Kudielka, Gaab, Schommer, & Hellhammer, 1999). The other exclusion criteria were: (a) being aged younger than 18 and older than 30 years; (b) being a regular smoker of cigarettes or a user of other tobacco products; (c) holding a diagnosis of a DSM-5 psychiatric disorder (American Psychiatric Association, 2013), or scoring ≥29 on the Beck Depression Inventory-Second Edition (BDI-II; Beck, Steer, & Brown, 1996); (d) being a current user of any steroid-based medication; (e) being non-South African and (e) having a body mass index (BMI) higher than 30 or lower than 16. The parameters of these eligibility criteria were chosen because they affect basal cortisol level and cortisol responsiveness to stress (Kudielka, Hellhammer, & Wüst, 2009; Barnes & Lewis, 2015).

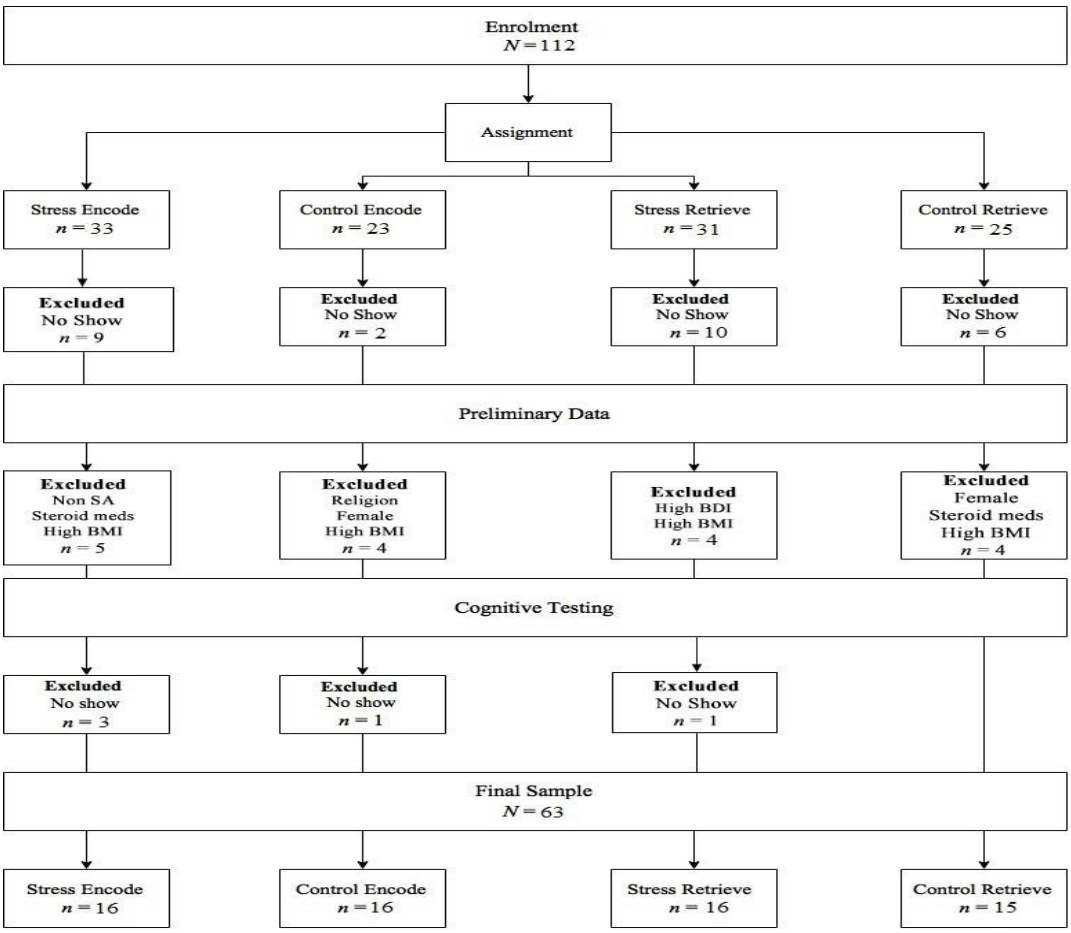

Figure 1. Participant attrition throughout the experimental protocol.

Materials.

Self-report measures.

Beck Depression Inventory-Second Edition (BDI-II). This instrument was used to screen for depressive symptoms in potential participants. Severely depressed individuals (i.e., those with a score ≥ 29) were excluded from participation. The BDI-II has a high level of internal consistency (α = .91), good test-retest reliability (α = .93), as well as adequate factorial and content validity (Barnes & Lewis, 2015; Beck et al., 1996; Dozois, Dobson, & Ahnberg, 1998).

State-Trait Anxiety Inventory (STAI). The STAI has two forms; the STAI-State and STAI-Trait. The STAI-State form measures anxiety at a specific time (State-anxiety), whereas the STAI-Trait form measures general anxiety levels (Trait-anxiety). Each form contains 20 statements, with responses being given on a 4-point Likert-type scale ranging from "not at all" to "very much so" for the STAI-State and from "almost never" to "almost always" for the STAI-Trait (Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983). Scores can range from 20 to 80 with high scores indicating high levels of anxiety. In this study, the STAI-Trait was used to ensure that the general level of anxiety of all participants across all experimental groups are similar. The STAI-State was used to measure changes in subjective anxiety levels during the experiment which was a measure of changing stress levels. No participants were excluded on the basis of having high STAI scores. This instrument has a reliable factor structure, good construct and concurrent validity, high internal consistency (α = .86 to .95), and high test-retest reliability (r = .69 to .89 over 2 months; Barnes & Lewis, 2015; Spielberger & Vagg, 1984).

Physiological measures.

Heart rate. I used the Vrije Universiteit Ambulatory Monitoring System, version 5fs (VU-AMS; Vrije Universiteit, Amsterdam, Holland), to capture heart rate data. This device is non-invasive and portable. The latter was particularly important because participants in the study were required to move around during the experimental procedures (Barnes & Lewis, 2015).

Experimental manipulation.

Fear Factor Stress Test (FFST). This laboratory-based acute psychosocial stressor (du Plooy, Thomas, Henry, Human, & Jacobs, 2014) combines the elements of social-evaluative threat (as present in the widely-used Trier Social Stress Test (TSST; Kirschbaum, Pirke & Hellhammer, 1993) and physiological challenge (as present in the widely-used Cold Pressor Test (CPT; Hines & Brown, 1932). The FFST was used as a stressor in this study as it

significantly elevates stress levels, and maintains them at high levels for up to 90 minutes post-stressor offset (Barnes & Lewis, 2015; du Plooy et al., 2014).

Experimental condition. Participants who were exposed to the FFST completed three tasks in front of two judges (one man and one woman) and a video camera: (1) a motivational speech; (2) a verbal serial subtraction task; and (3) a task that required submerging of the dominant arm in ice water for as long as possible (up to a maximum of 2 minutes; Barnes & Lewis, 2015; du Plooy et al., 2014).

Control condition. Participants not exposed to the stressor completed three tasks similar in nature to the FFST, but devoid of stressful elements: (1) writing about their day's activities for 10 minutes; (2) reading aloud, in a room alone, for 5 minutes; and (3) submerging the dominant arm in warm water (34-38 °C) for up to 2 minutes (Barnes & Lewis, 2015; du Plooy et al., 2014).

Working memory task: The *n*-back. This task was used to measure the participant's WM capacity. In the *n*-back test, participants are required to match the currently presented stimulus (a letter or word) to a stimulus presented *n* items before, where *n* usually varies between 1 and 3 (Conway, Kane, & Engle, 2003; Kirchner, 1958). The *n*-back task used in this study was created using E-Prime software (Psychology Software Tools, Pittsburgh, PA). This task had three levels; the zero, one and three-back presented across 9 blocks of 24 trials. The first block consisted of zero-back trials where participants were asked to press the F key (on a keyboard) if the letter X is presented and to press the J key for any other letters. Thereafter, the remaining blocks alternated between one-back and three-back trials. For the one-back trials, participants were asked to press the F key if the letter presented resembled a letter presented one before and to press J key if it did not. Likewise, for the three-back trials, participants were asked to press the F key if the letter presented resembled a letter present 3 back and to press the J key if it did not. Before administering the *n*-back task, participants were allowed a set of practice trials, with a criterion of 80% success required before they were permitted to move to the experimental task (Barnes & Lewis, 2015)..

Prospective memory tasks.

Laboratory event-based PM task. The present study used an English version of Walser et al.'s (2013) computerized event-based PM task. The on-going task consisted of classifying words as describing either animate or inanimate objects by pressing either the *F* or *J* keys on a standard computer keyboard. The words were presented on a standard computer screen, one at a time with an interval of 5 seconds between words. The PM task required the participant to press the spacebar when two specific words (one animate and one inanimate),

which were encoded during the first session, were presented. The task was presented across four cycles, each containing one PM block. A dataset of 11 animate and 11 inanimate words was created from the neutral set of Affective Norms for English Words list (Bradley & Lang, 1999), and was matched on initial letter and word length. These words were presented in random order four times (Barnes & Lewis, 2015).

Laboratory time-based PM task. An Android© application, designed specifically for the purposes of this study and compatible with a 7-inch Samsung Tablet, was used to assess time-based PM performance. The application featured a running clock and a log button underneath it. The participant was asked to monitor the time and press the log button every 1 minute. This instruction was encoded during the first session. This task ran concurrently with the event-based PM task (Barnes & Lewis, 2015).

Naturalistic event-based PM task. At the end of the first test session, participants were instructed to say their name and student number at the end of each cognitive task during the second session. During the second sessions, before each cognitive task started, participants were told that they will be completing a cognitive task and this was the environmental PM cue needed to trigger event-based PM (Barnes & Lewis, 2015).

Naturalistic time-based PM task. At the end of the first session, participants were instructed to send an email to the researcher at exactly 9am the following day. They were told that the email should contain their name, student number, and a confirmation of intention to attend the second session (Barnes & Lewis, 2015).

Procedure

Each participant was tested individually. So as to control for variations in baseline cortisol levels, participants in the SEDR and REDR groups were asked not to eat or to drink anything (except water) or participate in any physical activities at least 2 hours before their first session (Kudielka et al., 2009). The same was asked of participants in the EDSR and EDCR groups before their second session (Barnes & Lewis, 2015).

Upon arrival at the first test session, the participant read and sign the informed consent document, and then completed the BDI-II and STAI-Trait questionnaires. Thereafter, he was measured and weighed so that BMI could be calculated. Participants who met the BDI-II and BMI inclusion criteria then proceeded to the next stage of the experimental procedures. Those who did not were thanked for their participation, awarded 1 SRPP point, and dismissed. Those with BDI-II scores ≥ 29 were given contact information for the UCT Student Wellness Centre (Barnes & Lewis, 2015).

Experimental manipulation before encoding. The Day 1 session for participants in the SEDR and REDR groups lasted ±65 minutes (see Figure 2). During task practice, participants were administered both the practice on-going categorisation task and the practice *n*-back task. They were then administered the experimental *n*-back task. During the PM task encoding, participants encoded the instructions for both laboratory and naturalistic PM tasks. This session ended with the researcher reminding the participants of their appointment the next day. During the Day 2 session, these participants only completed the time- and event-based PM tasks. This session lasted ±30 minutes (Barnes & Lewis, 2015).

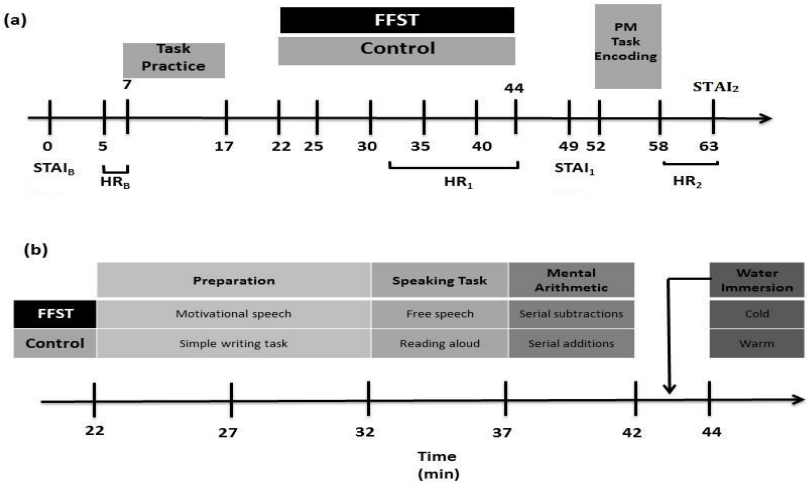

Figure 2. Day 1 experimental procedures for participants in SEDR and REDR groups. FFST = Fear Factor Stress Test; $STAI_B$ = baseline measurement, STAI-State; HR_B = baseline measurement, heart rate. $STAI_1$ = post-manipulation measurement, STAI-State; HR_1 = post-manipulation measurement, heart rate. $STAI_2$ = end-of-session measurement, STAI-State; HR_2 = end-of-session measurement, heart rate.

Experimental manipulation before retrieval. The Day 1 session for participants in the EDSR and EDCR groups lasted ±30 minutes. During that session, they were administered the practice ongoing task, the practice *n*-back, and the experimental *n*-back, in that order. They then encoded the instructions for both the naturalistic and laboratory PM tasks. The session ended with a reminder of their appointment the next day. The Day 2 session for those participants lasted ±90 minutes (see Figure 3) (Barnes & Lewis, 2015).

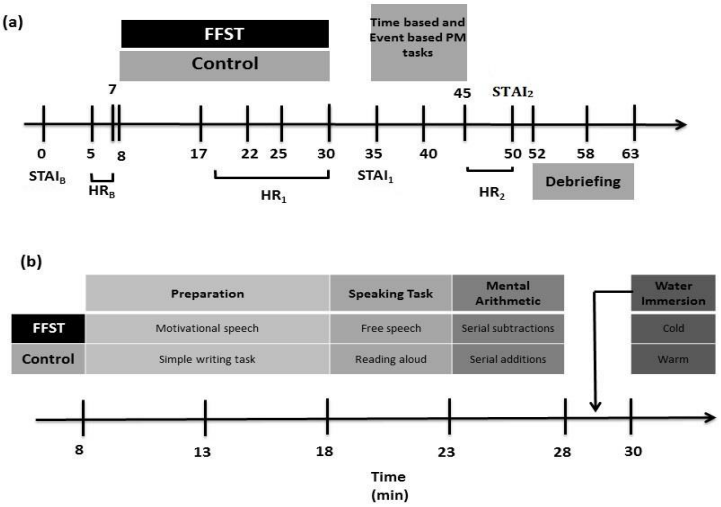

Figure 3. Day 2 experimental procedures for participants in the EDSR and EDRR groups. FFST = Fear Factor Stress Test; $STAI_B$ = baseline measurement, STAI-State; HR_B = baseline measurement, heart rate. $STAI_1$ = post manipulation measurement, STAI-State; HR_1 = post-manipulation measurement, heart rate. $STAI_2$ = end-of session measurement, STAI-State; HR_2 = end-of-session measurement, heart rate.

Debriefing. All participants were completely debriefed at the conclusion of the second session. Participants who had been exposed to the FFST were told that the video camera was fake, that they were not being recorded, and that the judges were not behavioral specialists. They were also told that this deception was needed so as to effect an increase in their cortisol levels. Details of a clinical psychologist were also provided to them (Barnes & Lewis, 2015).

Data Management and Statistical Analyses

I used SPSS version 23.0 to analyze the data. The threshold for statistical significance was set at .05. The required assumptions of each statistical analysis were upheld, unless stated otherwise within the Results section.

Sample characteristics. One-way ANOVAs were applied to the data for age, BMI, BDI-II, and STAI-Trait scores. The BDI-II and STAI-Trait scores were also compared to the normative data provided in their respective manual, using single-sample *t*-tests.

Experimental manipulation check. To confirm that the FFST was an effective stress-induction tool in this study, 2x2x3 (Experimental Condition [stress vs. relaxed] x Memory Phase [encoding vs. retrieval] x Measurement Point [baseline vs. post-manipulation vs. end of session]) repeated-measures ANOVAs analyzed self-report (STAI-State) and physiological (heart rate) data.

Testing Hypothesis 1. A series of one-way ANOVAs (Experimental Condition [stress vs. relaxed]) investigated differences in PM performance (both time- and event-based), one for each outcome variable (i.e., reaction time, error rate, reaction time error and accuracy).

Testing Hypothesis 2. For this analysis, the dataset was split into stress and relax conditions. Only the data from participants who had been exposed to the FFST were analyzed here. A series of one-way ANOVAs (Memory Phase [encoding vs. retrieval]) compared PM performance (both time- and event-based) of the SEDR and EDSR groups, one for each outcome variable (i.e. reaction time, reaction time error, accuracy and error rate)

Testing Hypothesis 3: Two paired samples *t*-tests, one for laboratory-based PM tasks and one for naturalistic PM tasks, were conducted to compare the mean for time-based PM performance and event-based PM performance.

Testing Hypothesis 4. A regression-based analysis tested this hypothesis, predicting accuracy on time-based PM tasks from WM capacity. Because accuracy on naturalistic time-based PM task was measured using a dichotomous outcome variable, I conducted a logistic regression analysis to test the same hypothesis.

Testing Hypothesis 5. A regression-based analysis, following steps described by Baron and Kenny (1986), tested whether WM capacity mediates the relationship between stress and PM performance. The steps followed for this analysis were as follows: First, PM performance was predicted from STAI-State scores at post-manipulation. If this model was significant, WM capacity was predicted from these STAI-State scores. If this model was also significant, then a multiple regression, featuring STAI-Scores at post-manipulation and WM capacity as predictors, and PM performance as outcome variable, was run. Finally, the Sobel (1982) test was used to test whether the mediating effect is statistically significant

Results

Final Sample Characteristics

Analyses of these characteristics sought to ensure that, across groups, the participants in the final sample were drawn from a similar population. Table 2 provides a summary of the relevant descriptive statistics.

Table 2.
Final Sample Characteristics: Descriptive statistics (N = 63)

Variable	Group			
	SEDR (*n = 16*)	EDSR (*n = 16*)	CEDR (*n = 16*)	EDCR (*n = 15*)
Age	20.75 (2.11)	21.69 (1.40)	21.81 (1.80)	20.27 (1.34)
BMI	23.11 (2.28)	24.27 (2.29)	25.47 (2.26)	25.37 (3.08)
BDI-II	5.06 (4.04)	7.44 (5.07)	10.00 (6.21)	10.53 (6.13)
STAI-Trait	34.13 (9.99)	39.38 (10.14)	38.75 (9.57)	39.87 (8.68)

Note. Data provided in this table are means, with standard deviations in parentheses. SEDR = Stress-Encode-Delay-Retrieve; EDSR = Encode-Delay-Stress-Retrieve; CEDR = Control-Encode-Delay-Retrieve; EDCR = Encode-Delay-Stress-Retrieve.

Age. Participants were aged between 18 and 26 years (M = 21.14 ± 1.78). The one-way ANOVA detected a statistically significant main effect of Group, $F(3, 60) = 3.00$, p = .038, η_p^2=.132. However, this significant difference in mean age across the four groups is not alarming. All participant ages fell within the range defined by the eligibility criteria, and hence it is unlikely that this statistically significant difference could confound the results.

BMI. Participant BMI ranged from 18.90 to 29.80 (M = 24.54 ± 2.61). The one-way ANOVA detected a statistically significant main effect of Group, $F(3, 59) = 3.11$, p = .033, η_p^2=.137. Again, this statistically significant between-group difference in mean BMI scores is no reason for concern because all BMI scores fell within the range defined by the eligibility criteria, and hence any differences are unlikely to confound the results.

BDI-II. Participant BDI-II scores ranged from 0 to 22. The mean score for each of the four groups fell within the range described conventionally as "minimally depressed" (i.e., < 19; Beck et al., 1996). The one-way ANOVA detected a statistically significant main effect of Group, $F(3, 59) = 3.41$, p = .023, η_p^2=.148. Because the eligibility criteria were applied rigorously, each BDI-II score fells below the threshold for exclusion (≥ 29), and hence this statistically significant between-group difference is unlikely to confound the results.

The single sample t-test comparing this sample's mean BDI-II score (M = 8.22 ± 5.73) to the normative data for college students provided by the BDI-II manual (M = 12.56 ± 9.93; Beck et al., 1996) detected a statistically significant difference, $t(62) = -6.01$, $p < .001$. Given the direction of the effect, this difference does not pose a confounding problem for the current study.

STAI-Trait. Participant STAI-Trait scores ranged from 22 to 57. The one-way ANOVA detected no significant between-group differences, $F(3, 59)= 1.19$, p = .320, η_p^2=.057. This result suggests there are similar levels of general anxiety across the four groups, and hence there are no pre-existing group-based differences in that trait that could affect the results of this study.

The single sample t-test comparing this sample's mean STAI-Trait score (M = 38.00 ± 9.67) to the normative data for men provided by the STAI manual (M = 38.30 ± 9.18; Spielberger et al., 1983) detected no statistically significant difference, $t(62) = -0.25$, p=.400. Hence, on average, this sample's STAI-Trait scores were not significantly higher than those

of the general population, and one can proceed with confidence in interpreting the results of the STAI-State administrations.

Experimental Manipulation Check

Table 3 provides a summary of the descriptive statistics for the relevant self-report and physiological measures. Note that seven sets of HR data were missing due to hardware malfunction.

Table 3.

Descriptive Statistics for Self-Reported and Physiological Measures of Stress (N = 63)

	Experimental Condition			
Measure	SEDR (n = 16)	EDSR (n = 16)	CEDR (n = 16)	EDCR (n = 15)
STAI-State				
Baseline	29.06 (7.47)	34.19 (9.35)	31.50 (7.58)	32.87 (7.18)
Post-manipulation	39.06 (12.68)	44.06 (12.97)	32.31 (8.79)	35.40 (11.12)
End of session	32.19 (8.25)	38.00 (11.79)	33.69 (10.40)	36.07 (13.84)
Heart rate (bpm)				
Baseline	76.28 (14.12) [a]	80.49 (19.89) [b]	74.85 (12.32) [c]	76.52 (13.69) [c]
Post-manipulation	95.93 (21.62) [a]	99.99 (19.63) [b]	77.25 (11.39) [c]	78.69 (10.79) [c]
End of session	76.39 (11.99) [a]	78.98 (14.28) [b]	72.71 (9.96) [c]	73.28 (9.86) [c]

Note. Data are means, with standard deviation in parentheses. [a]n = 15. [b]n = 13. [c]n = 14. SEDR = Stress-Encode-Delay-Retrieve; EDSR = Encode-Delay-Stress-Retrieve; CEDR = Control-Encode-Delay-Retrieve; EDCR = Encode-Delay-Stress-Retrieve.

STAI-State. The analysis detected a significant main effect of Measurement Point, $F(2, 118) = 14.74$, $p < .001$, $\eta_p^2 = .200$, and a significant Experimental Condition x Measurement Point interaction, $F(2, 118) = 9.10$, $p < .001$, $\eta_p^2 = .134$. It did not detect any other significant main or interaction effects, ps > .899, η_p^2s = .002.

Post-hoc pairwise comparisons exploring the significant effects suggested that, at baseline, STAI-State scores of participants exposed to the stressor (i.e., those in the SEDR and EDSR groups) were not significantly different to those of unexposed participants (i.e., those in the CEDR and EDCR groups), $t(59) = -0.28$, $p = .782$. Similarly, there were no statistically significant difference within the stress groups (SEDR/EDSR), $t(59)=-1.23$, $p=.224$ and the control groups (CEDR/EDCR), $t(59)=-75$, $p=.459$ at post-manipulation. However, participants exposed to the stressor self-reported a significant increase in state anxiety from baseline ($M = 31.62 \pm 1.42$) to post-manipulation ($M = 41.56 \pm 2.04$), $p < .001$, whereas participants not exposed to the stressor did not, $p = .275$.

Heart rate. Mauchly's test of sphericity was violated, $\chi^2(2) = 15.24$, $p < .001$, and so I used Greenhouse-Geisser estimates of sphericity ($\varepsilon = .795$) to correct the degrees of freedom so as to get a more accurate p-value. The subsequent analysis detected a significant main effect of Measurement Point, $F(1.59, 82.65) = 65.99$, $p < .001$, $\eta_p^2 = .559$, and a significant Experimental Condition x Measurement Point interaction, $F(1.59, 82.65) = 31.46$, $p < .001$, $\eta_p^2 = .377$. It did not detect any other significant main or interaction effects, ps > .776, η_p^2s < .004.

Post-hoc pairwise comparisons exploring the significant effects suggested that, at baseline, heart rate levels of participants exposed to the stressor (i.e., those in the SEDR and EDSR groups) were not significantly different to those of unexposed participants (i.e., those in the CEDR and EDCR groups), $t(52) = 0.67$, $p = .509$. Similarly, there were no significant differences within the stress groups, $t(52) = -.64$, $p = .522$ and relax groups, $t(52) = -.23$, $p = .819$ at post-manipulation. However, participants exposed to the stressor experienced a significant heart rate increase from baseline ($M = 78.23 \pm 2.83$) to post-manipulation ($M = 97.81 \pm 3.10$), $p < .001$, whereas participants not exposed to the stressor did not, $p = .266$.

Interim summary. Analyses of the STAI-State and heart rate data suggest the FFST significantly elevated stress levels in participants who were exposed to it, and that self-reported state anxiety and heart rate levels were not elevated above baseline levels in participants assigned to the control conditions. Hence, the experimental manipulation was successful.

Testing Hypotheses 1-5

Table 4 provides a summary of the relevant descriptive statistics. For the laboratory-based time-based PM task, the outcome variables were accuracy and reaction time (RT) error. The percentage of correctly logging the time every minute was used to calculate accuracy, and RT error was derived from the difference between expected log time and executed log time (in milliseconds). For the laboratory-based event-based PM task, the outcome variables were error rate (ER) and RT. ER was calculated as the percentage of incorrect responses. For RT, the unit of measurement for reaction time was again milliseconds. For the naturalistic event-based PM task, the outcome variable was accuracy, measured using an absolute score ranging from 0-4. For the naturalistic time-based PM task, the outcome variable was accuracy, measured using a binary (0 or 1) score (Barnes & Lewis, 2015). WM capacity was measured using accuracy of performance on the 3-back test. I used the STAI-State post-manipulation score to capture the degree to which acute stress was provoked. There are 2 missing data for laboratory time-based PM performance measures and 4 WM data missing for the 3 back task. These missing data are due to hardware malfunction.

Table 4.

Descriptive Statistics for Prospective Memory and Working Memory Tasks (N = 63)

	Experimental Condition			
	SEDR	EDSR	CEDR	EDCR
Outcome variable	(*n* = 16)	(*n* = 16)	(*n* = 16)	(*n* = 15)
Laboratory-based PM tasks				
Time-based				
Accuracy	.41 (.44)	.47 (.50)	.68 (.30)	.43 (.42)[a]
Reaction time error	1.66 (4.97)	0.76 (1.59)	0.54 (1.15)	0.83 (1.51)[a]
Event-based				
Error rate	.26 (.35)	.47 (.36)	.23 (.27)	.38 (.34)
Reaction time	1088.96 (149.71)	1064.63 (433.91)	1056.25 (272.99)	1038.18 (168.10)
Naturalistic PM tasks				
Time-based				
Accuracy	.63 (.50)	.38 (.50)	.87 (.34)	.60 (.51)
Event-based	1.50 (1.63)	1.62 (1.75)	2.06 (1.81)	1.60 (1.84)
Accuracy				
n-back				
3-back accuracy	86.67 (6.78)[a]	85.24 (8.26)[a]	86.40 (8.91)[a]	80.70 (13.07)[a]

Note. Data are means, with standard deviation in parentheses. [a]*n*=14. SEDR = Stress-Encode-Delay-Retrieve; EDSR = Encode-Delay-Stress-Retrieve; CEDR = Control-Encode-Delay-Retrieve; EDCR = Encode-Delay-Stress-Retrieve; PM = prospective memory.

Hypothesis 1: Effects of stress on PM performance

Laboratory-based tasks. The series of one-way ANOVA conducted to test this hypothesis detected no statistically significant effect of Experimental Conditions on the outcome variables for both time- and event-based PM tasks, *p*s > .445, η_p^2s < .01.
The assumption of homogeneity of variance was violated when running the analysis for Time-Based accuracy, Levene's Test, $F(1, 60) = 7.16$, $p = .006$. Due to this, an independent samples *t*-test, with unequal variance assumed, was run to compare the means of stress and relax conditions for time-based accuracy. This analysis detected no statistically significant difference in accuracy across the stress and relaxed conditions for the time-based PM task, $t(58.79)=-1.18$, $p=.245$, $d = -.125$.

Naturalistic tasks. The result of the analysis conducted shows that Experimental Conditions had no statistically significant effect on the accuracy of participants on Naturalistic event-based PM tasks, $F(1, 61) = .40$, $p = .530$, $\eta_p^2=.006$. However, it detected a statistically significant effect of Experimental Conditions on the accuracy of participants on the Naturalistic time-based PM task, $F(1, 61) = 4.03$, $p = .049$, $\eta_p^2 = .062$. In other words, participants in the stress condition were less accurate ($M=.50 \pm .51$) when sending the required email as compared to participants in the control condition ($M = .74 \pm .45$).

Hypothesis 2: Effects of stress at encoding versus retrieval. Recall that only data from participants who had been exposed to the FFST were analyzed here.

Laboratory-based PM performance. The series of one-way ANOVA conducted to test this hypothesis detected no statistically significant effect of Memory Phase on the outcome variables for both time- and event-based PM tasks, *p*s > .103, η_p^2s < .086. In other words, whether stress was induced at encoding or retrieval had no effect on the performance on both time- and event-based PM tasks.

Naturalistic PM performance. With regards to Time-based PM performance, the one-way ANOVA showed that the Memory Phase at which stress was induced; either at encoding or retrieval, had no effect on the accuracy of participants in performing the Naturalistic Time-Based Task, $F(1,30)= 2.00$, $p = .168$, $\eta_p^2 = .062$. In terms of Event-Based PM performance, the one-way ANOVA also did not detect any statistically significant effect of Memory Phase at which stress was induced on the participants' accuracy, $F(1,30) = .04$, $p = .836$, $\eta_p^2 = .001$.

Hypothesis 3: Performance on time-based versus event-based PM tasks. For this analysis, the outcome variable was accuracy on the time- and event-based tasks. For the laboratory-based tasks, I inverted the values for error rate on the event-based tasks so as to produce a measure of accuracy comparable to that from the time-based task. For the

naturalistic tasks, the absolute scores for the event-based task were converted into a percentage of the maximum score so as to be comparable to the binary score for the time-based task.

Laboratory-based tasks. The paired-samples *t*-test detected a significant between-task difference, $t(61) = 2.52$, $p < .001$. Perusal of the means suggested that accuracy on the time-based task was worse than that on the event-based task ($M = .50 \pm .42$ versus $.67 \pm .34$).

Naturalistic tasks. The paired-samples *t*-test detected a significant between-task difference, $t(62) = 2.43$, $p < .001$. Perusal of the means suggested that accuracy on the time-based task was better than that on the event-based task ($M = .62 \pm .49$ versus $.43 \pm .43$).

Hypothesis 4. The simple linear regression analysis testing whether WM capacity accounted for a substantial amount of the variance in performance on the laboratory-based time-based PM task was not significant, $R^2 = .02$, $F(1, 55) = .99$, $p = .323$. The logistic regression run to test the relationship between WM capacity and performance on naturalistic time-based PM task was also not significant, Cox & Snell $R^2 = .01$, $\chi^2(1) = .31$, $p = .575$.

Hypothesis 5. The variable used for PM performance was accuracy on PM tasks. 5 WM data was missing due to hardware malfunction.

Laboratory-based PM tasks. Acute stress, as measured by the STAI-State post-manipulation score, was not a significant predictor of PM performance on accuracy on either event-based or time-based PM tasks, $R^2 = .04$, $F(1, 61) = 2.31$, $p = .134$, and $R^2 = .002$, $F(1, 60) = .13$, $p = .724$, respectively. Because these models were not statistically significant, exploration of possible mediation concluded at this step.

Naturalistic PM tasks. Regarding the event-based task, STAI-State post-manipulation score was not a significant predictor of PM accuracy, $R^2 = .002$, $F(1, 61) = .11$, $p = .740$. Because this model was not statistically significant, exploration of possible mediation concluded at this step.

Regarding the time-based task, a logistic regression model suggested that STAI-State post-manipulation score was a significant predictor of PM accuracy, Cox & Snell $R^2 = .11$, $\chi^2(1) = 6.96$, $p = .008$. However, STAI-State post-manipulation score was not a significant predictor of 3-back accuracy, $R^2 = .01$, $F(1, 56) = .28$, $p = .597$. Because this model was not statistically significant, exploration of possible mediation concluded at this step.

Discussion

The overall aim of this study was to add to the literature on PM, Stress and WM by testing the effects of acute psychosocial stress across different phases of PM processing (i.e., encoding/retention and retrieval/execution), for both time-based and event-based PM tasks,

and (b) the effect of WM memory capacity on time-based PM performance (c) possible mediating effects of WM capacity on the relationship between stress and PM. As such, this study attempted to test the following hypotheses:

6) Under conditions of acute stress, participants will have poorer time- and event-based PM performance than under normal conditions;
7) When acute stress is induced at encoding, PM performance will be poorer than when acute stress is induced at retrieval;
8) Under all conditions, participants' performance on time-based PM tasks will be poorer than on event-based tasks;
9) Under all conditions, time-based PM performance will increase when WM capacity increases.
10) WM capacity, as measured by performance on an *n*-back task, will mediate the effects of stress on both time- and event-based PM performance.

Summary and Implications of Results

The first major set of findings suggests that PM performance is, in general, rather robust to the effects of acute psychosocial stress. Participants who were exposed to an acute psychosocial stress, in the form of the Fear Factor Stress Test (FFST; du Plooy et al., 2004) did not perform more poorly, on laboratory-based time- and event-based PM tasks and on naturalistic event-based tasks, than participants who were exposed to the non-stressful control condition. These findings on laboratory-based event-based PM performance are consistent with reports by Nakayama et al. (2005), Nater et al. (2006), and Walser et al. (2013), all of whom found that acute psychosocial stress had no significant effect on laboratory-based event-based PM performance. The current findings go beyond those, however, in suggesting that the performance of an event-based task under naturalistic conditions might not be affected by exposure to an acute psychosocial stressor.

The current study did find, however, that acute psychosocial stress did have a significant negative effect on the performance of a naturalistic time-based PM task; a larger group of participants exposed to the FFST did not send the required email as compared to those exposed to the control conditions. This result stands in contrasts to that of Nater et al. (2006), who reported that their acute psychosocial stressor *enhanced* time-based PM performance on a laboratory task. One possible, and obvious, reason for the disparity between these two findings is that the task in the current study was based in a naturalistic, and not a laboratory, setting. This difference in PM performance between naturalistic and laboratory PM tasks is supported by the age prospective memory paradox. The age prospective memory

paradox stems from the fact that several studies found that younger adults tend to outperform older adults in laboratory PM tasks but older adults tend to outperform younger adults in naturalistic PM tasks (see e.g. Henry, Macleod, Phillips, & Crawford, 2004; Rendell & Craik, 2000). Regardless of the age-difference factor being absent, our study also showed that a difference exists in the performance of time-based PM tasks when the task is performed in a naturalistic or a laboratory setting. Two possible reasons given by Rendell and Craik (2000) to explain the age prospective memory paradox is time and motivation. One major difference between naturalistic and laboratory PM tasks is that for naturalistic PM tasks, there is usually a longer delay between encoding and retrieval of PM intentions. They believed that younger participants were better on laboratory PM tasks as they are better at remembering PM intentions over short period of time given a motivation and no other important tasks to intervene (Rendell & Craik, 2000). As such, the difference in performance on our naturalistic PM task and the laboratory PM task of Nater and colleagues can be explained by the fact that there was a delay of 24-hours in our study and participants had other important tasks to attend to in this 24-hour delay. Nonetheless, the findings from the current study provide a warning about PM tasks in everyday life: Someone who is faced with stressful conditions may, for instance, forget to take a required medication at a certain time.

The second major set of findings suggests that the memory phase at which acute psychosocial stress is introduced has no significant effects on PM performance. That is to say, participants exposed to the FFST performed just as well on time- and event-based PM tasks, in the laboratory and in naturalistic settings, when the stressor was introduced immediately prior to encoding as when it was introduced immediately prior to retrieval. This finding disconfirmed the a priori hypothesis, which was based largely on data from studies investigating the effects of stress on retrospective memory performance. For instance, Cornelisse et al. (2011) reported that exposure to acute psychosocial stress can either enhance or weaken memory performance, depending on the type of memory (e.g., Retrospective vs Prospective) and memory phase (e.g., encoding versus retrieval). Similarly, Roozendal (2002) showed, in a retrospective memory paradigm, that exposure to stress enhances encoding of new information but disrupts the retrieval of previously-learned information (Roozendal, 2002). Because PM comprises a retrospective and a prospective memory component, one might expect that acute stress should have an effect on PM performance, especially if induced immediately prior to retrieval.

The third major set of findings suggests that, in terms of accuracy on laboratory-based PM tasks, all participants (regardless of group membership) tended perform more poorly on

the time-based task than on the event-based task. In contrast, in terms of accuracy on naturalistic PM tasks, they tended to perform better on the time-based task than on the event-based task. The contrast in these findings provides additional evidence of the difference between laboratory PM tasks and naturalistic PM tasks. In this situation, the difference may stem from the fact that participants might have used reminders to send the email at the required time (PM instruction for naturalistic time-based PM task). Since, Ihle, Schnitzpahn, Rendell, Luong and Kliegel (2011) has shown that use of reminders tend to improve PM performance in general, this might have caused the better performance in naturalistic time-based PM as compared to the time-based PM task in the laboratory PM task.

This contrast between performance on laboratory-based and naturalistic PM tasks illustrates the importance of creating ecologically valid PM tasks. Ecologically valid tasks that measure executive functions such as PM would allow us to accurately predict the cognitive abilities of an individual in everyday life. It would also be clinically relevant as it would allow us to predict the cognitive abilities of an individual after a brain injury (Chaytor, Schmitter-Edgecombe, & Burr, 2005). Since PM is such an important construct in our everyday lives, having such ecologically valid tasks would allow us to measure the PM abilities of an individual and provide training where it is needed. As such, we would be able to decrease PM mistakes in situations where is important such as in the case of an air traffic controller.

The fourth major set of findings suggests that WM capacity is not significantly associated with performance on time-based PM tasks, regardless of whether those tasks are laboratory-based or naturalistic. Taken together with the findings described above, this set of findings cannot be accounted for by theories suggesting that time-based PM tasks require more executive resources than event-based PM tasks (Williams et al., 2014).

Finally, this study attempted to add novel information to the literature by testing the mediating effect of WM capacity on the relationship between acute psychosocial stress and PM performance. The analyses suggested that such a mediating effect is not present (or, at least, is not detectable within the current design and current sample). The reason for this is that a large sample size (as large as 20,866) is needed to achieve adequate power for the mediation analysis run in this study (Fritz & MacKinnon, 2007). One valuable piece of information that can be taken from this finding, however, is that acute psychosocial stress might not have an effect on WM performance. This contrasts with the findings of Schoofs, Preub and Wolf (2008) who found significant working memory impairment for both 2-back and 3-back workloads when participants were exposed to stress.

Limitations

The following factors constitute limitations of the study (either internal (e.g., the design) or external (e.g., time constraints on data collection). These must be considered as one interprets the data and attempts to apply them to real-world situations.

First, although I collected a full set of salivary cortisol samples, the National Health Services Laboratory at Groote Schuur Hospital was not able complete analysis of them before the time of writing. Hence, I had to use only a self-report measure (STAI-State) and a single physiological measure (heart rate) as indicators of FFST effectiveness. As reliable as these variables can be, the general consensus in the literature is that cortisol is the most reliable, and neurobiologically valid, index of stress in humans (Kirschbaum & Hellhammer, 1989). This is, at least in part, because the hormone binds to glucocorticoid receptors in areas that are important for PM performance (e.g., the prefrontal cortex; Arnsten, 2011), thus having a direct effect on whether the individual completes the task optimally or not (Walser et al., 2003).

In mitigation of this limitation is the fact that previous studies in our laboratory (e.g., Barnes & Lewis, 2015; du Plooy et al., 2014) have established that the FFST reliably raises cortisol levels, and maintains them at greater-than-baseline levels for at least an hour post-stressor offset. Hence, one might argue that the current analyses are justified in accepting that, on average, stress levels in the FFST-exposed participants were significantly higher than those in the control participants after completion of the experimental protocol. Certainly, however, future studies in this field should endeavor to collect cortisol samples, and to report on them.

A second limitation is that, by design, women were excluded from participation. Because one often finds sex differences in the effects of stress on cognitive performance (e.g., Cornelisse et al., 2011; Schoofs, Pabst, Brand, & Wolf, 2012; Thomas et al., 2010), I cannot confidently generalize the current findings to the female population. In mitigation of this limitation, however, is the fact that numerous published studies in this field (e.g. Nakayama et al., 2005) feature all-male samples, for much the same hormonal reasons as mine did. Nonetheless, future studies in this field should endeavor to collect data from both men and women, and should include sex as a factor in their data analyses.

A third limitation is that, by design, the study included a 24-hour unmonitored delay between encoding of the instructions for the PM task and retrieval of the intention to execute those instructions (Barnes & Lewis, 2015). The fact that I did not monitor participants during the delay means that I could not ensure that they did not record the PM instructions (on their smartphones, or on paper), rehearse them constantly, as an aid to retrieval. This potential

confound is difficult to control, but future studies might consider taking a subjective report of the strategies used by participants to remember PM instructions. This information could then inform the data analysis, or at least assure the researchers that instruction recording/rehearsal did not confound their results.

A fourth limitation applies as much to this study as to any within the field of PM research. Because research on prospective memory is still in its relative infancy, there are almost no standardized measures in the field. Although there are well-designed (and, sometimes, well-validated) measures used in experimental settings (Kliegel, McDaniel & Einstein, 2000), and although two self-report questionnaires, the Memory for Intentions Screening Test (MIST; Raskin, 2004) and the Prospective and Retrospective Memory Questionnaire (PRMQ; Smith, Della Salla, Logie & Maylor, 2000), there is no standard measure used widely in laboratory studies across the world. In the current study, the task used to measure laboratory-based event-based PM performance was adapted from Walser et al. (2013). The app used to measure laboratory time-based PM performance was created by a colleague specifically for this study. Hence, generalizing the current findings to other settings and populations, and comparing the current findings to those from other studies, is fraught with difficulty. The development, standardization, and norming of standardized PM measures would benefit both researchers and clinicians. For instance, it would simplify the task of cross-study comparisons, it would allow PM to be included as a key domain of assessment in clinical neuropsychological settings, and it would encourage cross-cultural explorations of variations in PM development.

Conclusion

Our findings show that acute psychosocial stress does not affect PM performance whether it is induced at encoding or retrieval. It also showed that there is no relationship between time-based PM performance and WM capacity. Both of these findings provide novel information to the literature as no other studies tested such hypotheses before. The mediating effect of WM capacity on the relationship between acute stress and PM could not be tested as the regression analysis run showed no statistical significance since the sample size is too small for the analysis run. However, this study also provided other interesting findings. For instance, it found that under stress, participants tend to make more PM mistakes in naturalistic time-based PM tasks than under normal conditions. Likewise, it found that across all conditions, performance in naturalistic time-based PM tasks is better than performance on naturalistic PM event-based tasks. In other words, people might still forget to perform a time-based task when under stress but across all conditions; stress or relaxed, they tend to be more

accurate at performing a time-based PM task than an event-based PM task. Despite these findings, our study show that PM is rather robust to the effects of acute stress. As we can see, research on PM can provide information that are essential for improving daily activities but PM research is still in its early stages and much more must be conducted on the different aspects of PM and its relationship with stress and WM.

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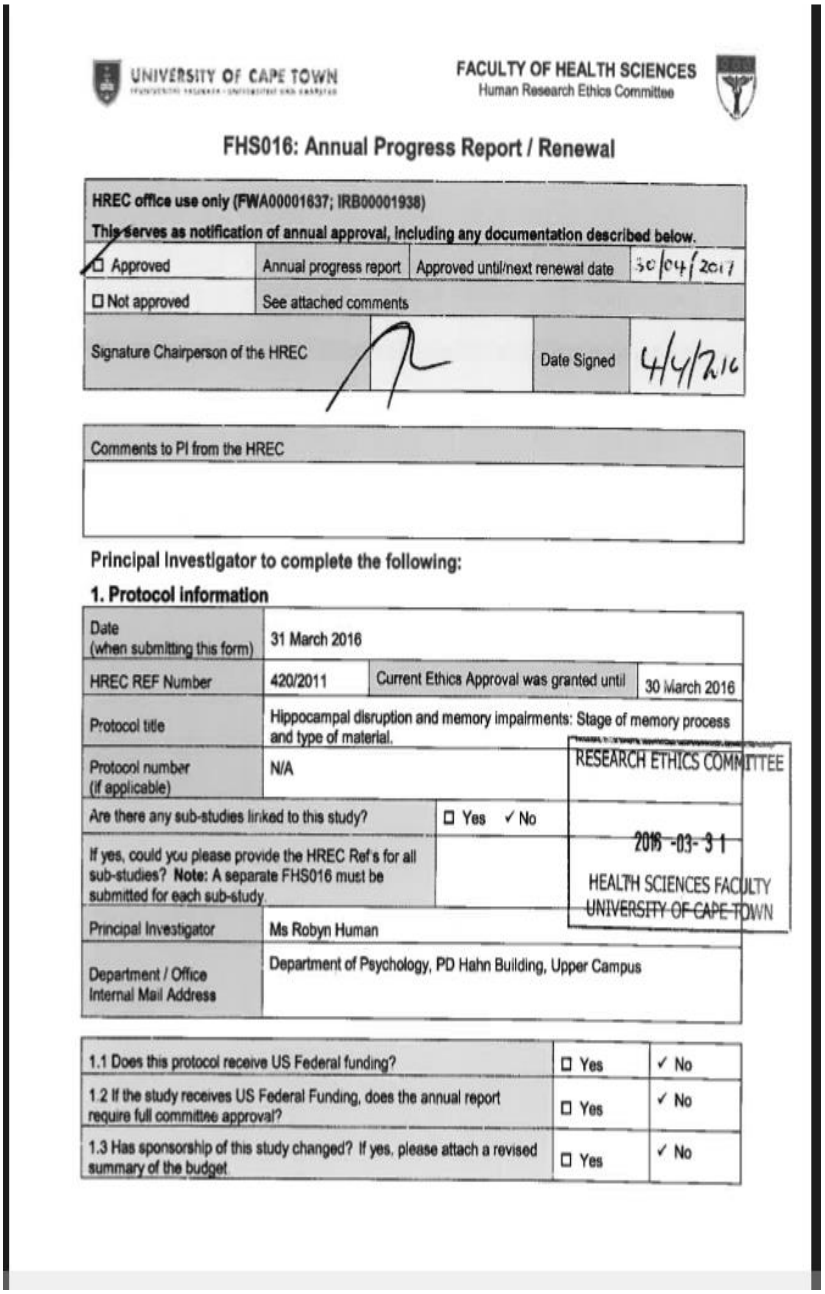
Appendix A

Faculty of Health Science Human Research Committee: Ethical Approval



UNIVERSITY OF CAPE TOWN

FACULTY OF HEALTH SCIENCES
Human Research Ethics Committee

FHS016: Annual Progress Report / Renewal

HREC office use only (FWA00001637; IRB00001938)			
This serves as notification of annual approval, including any documentation described below.			
☐ Approved	Annual progress report	Approved until/next renewal date	30/04/2017
☐ Not approved	See attached comments		
Signature Chairperson of the HREC		Date Signed	4/4/2016

Comments to PI from the HREC

Principal Investigator to complete the following:

1. Protocol information

Date (when submitting this form)	31 March 2016		
HREC REF Number	420/2011	Current Ethics Approval was granted until	30 March 2016
Protocol title	Hippocampal disruption and memory impairments: Stage of memory process and type of material.		
Protocol number (if applicable)	N/A		
Are there any sub-studies linked to this study?	☐ Yes ✓ No		
If yes, could you please provide the HREC Ref's for all sub-studies? **Note:** A separate FHS016 must be submitted for each sub-study.			
Principal Investigator	Ms Robyn Human		
Department / Office Internal Mail Address	Department of Psychology, PD Hahn Building, Upper Campus		

RESEARCH ETHICS COMMITTEE
2016 -03- 31
HEALTH SCIENCES FACULTY
UNIVERSITY OF CAPE TOWN

1.1 Does this protocol receive US Federal funding?	☐ Yes	✓ No
1.2 If the study receives US Federal Funding, does the annual report require full committee approval?	☐ Yes	✓ No
1.3 Has sponsorship of this study changed? If yes, please attach a revised summary of the budget	☐ Yes	✓ No

Appendix B

Consent Form

Informed Consent to Participate in Research

and Authorisation for Collection, Use, and

Disclosure of Protected Health Information

This form provides you with information about the study and seeks your authorisation for the collection, use and disclosure of your protected health information necessary for the study. The Principal Investigator (the person in charge of this research) or a representative of the Principal Investigator will also describe this study to you and answer all of your questions. Your participation is entirely voluntary. Before you decide whether or not to take part, read the information below and ask questions about anything you do not understand. By participating in this study you will not be penalised or lose any benefits to which you would otherwise be entitled.

1. Name of Participant ("Study Subject")

_____

2. Title of Research Study

The mediating variables of acute psychosocial stress on cognitive performance.

3. Principal Investigators, Ethics Committee, and Telephone Numbers

Kevin G. F. Thomas, Ph.D.
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University of Cape Town
021-650-4608

Robyn Human, MA
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4. What is the purpose of this research study?

The purpose of this research study is to better understand how exposure to acute psychological stress affects cognitive performance. More specifically, we are interested in what variables may mediate this relationship.

5. What will be done if you take part in this research study?

This study requires you to take part two research sessions on two consecutive days. During this study, you will be required to complete a number of memory based tasks and may be required to complete a 20 minute presentation. Your levels of stress will be assessed through the collection of self-report data, heart rate measurements, skin conductance measurements and saliva samples with the aid of a cotton swab. These saliva samples will be used to analyse levels of cortisol, a stress hormone.

6. What are the possible discomforts and risks?

If you are one of the participants selected to complete the 20 minute presentation, you may be placed in a mildly stressful situation involving public speaking. There are no other discomforts and risks associated with participation in the study.

7. What are the possible benefits of this study?

One major benefit of this study is that scientists and society in general, will have better understanding of the effects of acute psychological stress on cognitive performance, and what variables mediate this relationship. This knowledge can then be applied to many different individuals and situations, including students who are taking exams, business managers who have to present to their boards, and so on.

8. Can you withdraw from this research study and if you withdraw, can information about you still be used and/or collected?

You may withdraw your consent and stop participation in this study at any time. Information already collected may be used.

9. Once personal information is collected, how will it be kept confidential in order to protect your privacy and what protected health information about you may be collected, used and shared with others?

Information collected will be stored in locked filing cabinets or in computers with security passwords. Only certain people - the researchers for this study and certain University of Cape Town officials - have the legal right to review these research records. Your research records will not be released without your permission unless required by law or a court order.

If you agree to be in this research study, it is possible that some of the information collected might be copied into a "limited data set" to be used for other research purposes. If so, the limited data set may only include information that does not directly identify you.

Signatures

As a representative of this study, I have explained to the participant the purpose, the procedures, the possible benefits, and the risks of this research study; the alternatives to being in the study; and how the participant's protected health information will be collected, used, and shared with others:

_____ _____

Signature of Person Obtaining Consent Authorisation Date

You have been informed about this study's purpose, procedures, and risks; how your protected health information will be collected, used and shared with others. You have received a copy of this form. You have been given the opportunity to ask questions before you sign, and you have been told that you can ask other questions at any time.

You voluntarily agree to participate in this study. You hereby authorise the collection, use and sharing of your protected health information. By signing this form, you are not waiving any of your legal rights.

_____ _____

Signature of Person Consenting Authorising Date

Please indicate below if you would like to be notified of future research projects conducted by our research group:

_____ (initial) Yes, I would like to be added to your research participation pool and be notified of research projects in which I might participate in the future.

Method of contact:

Phone number: _____

E-mail address: _____

Mailing address: _____

_____

_____

Appendix C

Debriefing Form

Acute Psychosocial Stress and Prospective Memory: The Mediating Effect of Working Memory:

Debriefing Form

Thank you for participating in the research study.

This form provides you with information about the study in which you have just participated, and explains in full the methods of collection of data for this research study. The Principle Investigator (the person in charge of this research) or a representative of the Principle Investigator will also explain this study to you in full and answer your questions.

1. Name of Participant ("Study Subject")

_____

2. Title of Research Study

Acute psychosocial stress and prospective memory: The mediating effect of working memory

3. Principal Investigators, Ethics Committee, and Telephone Numbers

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4. What is the purpose of this research study?

The purpose of this research study is to better understand how exposure to acute psychological stress affects cognitive performance, more specifically memory and how this is mediated by Working Memory.

5. What was done during this research study?

During this study, you were required to complete a number of memory based tasks and may have been required to complete a 20 minute presentation. Your levels of stress were assessed through the collection of self-report data, heart rate measurements, skin conductance measurements and saliva samples with the aid of a cotton swab. These saliva samples will be used to analyse levels of cortisol, a stress hormone.

6. Was there any deception used in this research study?

If you were one of the participants selected to complete the 20 minute presentation, you will have been told that your verbal and non-verbal behaviour was being judged by a panel, and that you were being filmed in order to facilitate this evaluation. However, the panel was not judging you in any way, nor was the video camera actually recording your behaviour. Anything you said or did in the “interview” will be kept confidential. This deception was necessary in order to achieve the required increase in cortisol levels.

7. Is there anything further required of you?

Please do not disclose anything that happened during these research sessions to anyone else, as this may bias future participants and their performance.

If you are still feeling stressed at the end of the research study, please inform us so that we can provide you with the contact details of a clinical psychologist who can provide you with post-session counselling.

Signatures

As a representative of this study, I have explained to the participant, in detail, the purpose, the procedures, and any deception used in this research study.

_____ _____

Signature of Person Obtaining Consent Authorisation Date

I have been informed, in detail, about this study's purpose, procedures, and deceptions. I have been given the opportunity to ask questions before I sign. By signing this form, I am not waiving any of my legal rights.

_____ _____

Signature of Person Consenting Authorising Date