South African Journal of Psychology 43(3) 300–313 © The Author(s) 2013
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DOI: 10.1177/0081246313496913 sap.sagepub.com
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Article

Acute psychosocial stress enhances visuospatial memory in healthy males

Robyn Human, Kevin GF Thomas, Anna Dreyer, Alyssa R Amod, Pedro SA Wolf and W Jake Jacobs

Abstract

Previous research demonstrates that stress can disrupt a number of different cognitive systems, including verbal memory, working memory, and decision-making. Few previous studies have investigated relations between stress and visuospatial information processing, however, and none have examined relations among stress, visuospatial memory performance, and planning/organisation of visuospatial information simultaneously. In total, 38 undergraduate males completed the copy trial of the Rey-Osterrieth Complex Figure Test. Those assigned randomly to the Stress group (n = 19) were then exposed to a laboratory-based psychosocial stressor; the others were exposed to an equivalent control condition. All then completed the delayed recall trial of the Rey-Osterrieth Complex Figure Test. Physiological and self-report measures of stress indicated that the induction manipulation was effective. Our predictions that control participants, relative to stressor-exposed participants, (a) take less time to complete the Rey-Osterrieth Complex Figure Test recall trial, (b) reproduce the figure more accurately on that trial, and (c) show better planning and more gestalt-based organisational strategies in creating that reproduction were disconfirmed. At recall, those with *higher* circulating cortisol levels (measured post-stress-induction) completed the drawing more accurately than those with lower circulating cortisol levels. Otherwise stated, the present data indicated that exposure to an acute psychosocial stressor *enhanced* visuospatial memory performance in healthy males. This data pattern is consistent with a previously proposed inverted U-shaped relationship between cortisol and cognition: Under this proposal, moderate levels of the hormone (as induced by the current manipulation) support optimal performance, whereas extremely high and extremely low levels impair performance.

Keywords

Cortisol, hippocampus, memory, planning, prefrontal cortex, Rey-Osterrieth Complex Figure Test, stress, visuospatial

University of Cape Town, South Africa
University of Arizona, USA

Corresponding author:
Kevin GF Thomas, ACSENT Laboratory, Department of Psychology, University of Cape Town, Private Bag, Rondebosch 7701, South Africa.
Email: kevin.thomas@uct.ac.za

Stress is a part of everyday life. Regardless of source or severity, the perception and experience of a stressor[1] affects memory processing: Sometimes one goes blank during an examination, even though test preparation has been good, and sometimes one remembers an intense childhood trauma for a lifetime. Regardless of a stressor's nature and characteristics, exposure produces a coordinated set of physiological responses (Sapolsky, 2004).

The physiological stress response has two major pathways. The autonomic nervous system (ANS) response is rapid and leads to, for example, increased heart rate. The hypothalamic–pituitary–adrenal (HPA) axis response is slow and persistent; cortisol levels, for example, peak 20–40 min after a stressor begins and return to baseline 40–60 min after it ends (Alderson & Novack, 2002). HPA responding is relevant to brain–behaviour relations because of its responsibility for the release of glucocorticoids (cortisol, in humans).

Cortisol easily crosses the blood–brain barrier. In the brain, it affects the hippocampus, prefrontal cortex (PFC) and other regions containing high concentrations of cortisol-specific receptors (Putman & Roelofs, 2011). Acting at hippocampal receptors, cortisol changes characteristics of learning and memory; acting at PFC receptors, it changes characteristics of planning and organisation (Miller & Cohen, 2001; Squire, 1992).

Most studies in this field examine relations between stress and verbal declarative memory and conclude that exposure to laboratory-based psychosocial stressors impairs performance on such memory tasks (see, for example, Kirschbaum, Wolf, May, Wippich, & Hellhammer, 1996; Stawski, Sliwinski, & Smyth, 2009). Extant studies, which use different stress-induction and measurement methods, leave us with no consensus regarding relations between stress and visuospatial declarative memory: Some report enhancing effects (Luethi, Meier, & Sandi, 2009), others report impairing effects (Morgan, Doran, Steffian, Hazlett, & Southwick, 2006; Taverniers, Ruysseveldt, Smeets, & Grumbkow, 2010), and others report no detectable effects (Hoffman & al'Absi, 2004). Moreover, no published studies directly examine the impact of stress on planning and organisation of non-verbal stimuli. A small group of studies has, however, noted that stress affects PFC-related functions such as decision-making and working memory (Schoofs, Wolf, & Smeets, 2009; van den Bos, Harteveld, & Stoop, 2009).

Our purpose was to examine the impact of an acute psychosocial stressor on Rey-Osterrieth Complex Figure Test (ROCF; Osterrieth, 1944; Rey, 1941) performance. Whereas previous studies induced stress before administering a ROCF copy trial (encoding phase), we induced stress after the copy phase (i.e., during consolidation and retrieval). We did so because (a) inducing stress before encoding does not allow one to distinguish stress effects on encoding, consolidation, or retrieval, and (b) stress tends to affect the encoding phase most heavily, thus obscuring effects that might occur during consolidation and/or retrieval or that might affect other cognitive domains (Nadel & Moscovitch, 1997; Smeets, 2011).

We predict that control participants, relative to stressor-exposed participants, (a) take less time to complete the ROCF recall trial, (b) reproduce the figure more accurately on that trial, and (c) show better planning and more gestalt-based organisational strategies in creating that reproduction.

Methods

Participants

In total, 38 male undergraduates (18–23 years) participated. Based on the large effect size estimates (ESEs) previously reported (Taverniers et al., 2010), a power analysis indicated that this *N* is sufficient to detect the effects under consideration. Even if ESEs were in the medium range, the current *N* has excellent power (> .90).

We assigned each participant randomly to either a Control or a Stress group ($n = 19$ each). We used an all-male sample to avoid cortisol confounds associated with menstrual cycle stage and use of oral contraceptives (Kirschbaum, Kudielka, Gaab, Schommer, & Hellhammer, 1999; Kirschbaum, Pirke, & Hellhammer, 1995). Exclusion criteria were use of steroid-based medication, the presence of major affective disorders, or a body mass index (BMI) of <16 and >30. These variables also confound research investigating relations between psychosocial stress and cognitive performance (Kudielka, Hellhammer, & Wüst, 2009) and are consistent with criteria used elsewhere (Kirschbaum, Pirke, & Hellhammer, 1993; Maruyama et al., 2012).

All participants were recruited via our Department of Psychology's Student Research Participation Program (SRPP). This program requires undergraduate students to either, for each Psychology course in which they are registered, participate in 90 min of research or write a literature review. Hence, the participants who completed our study fulfilled the SRPP requirement for one of their Psychology courses, and the incentive for participating in our study was consistent with those of other studies in our department and with the department's educational aims. The Research Ethics Committees of the University of Cape Town's Department of Psychology and Faculty of Health Sciences granted ethical approval.

Materials and procedures

Consistent with protocols followed in other studies (e.g., Kirschbaum et al., 1993; Schoofs, Preuβ, & Wolf, 2008), participants received instructions, the day before the session, not to smoke, consume food or drink, chew gum, or engage in physical exercise for 2 hr before the start of the session. Experimental procedures occurred between 14h00 and 18h00 to control for cortisol's diurnal cycle (Kudielka et al., 2009). Figure 1 illustrates the timeline of events in the experimental procedure.

A research assistant (RA; a female postgraduate) met participants at the research laboratory. Participants read and signed a consent form immediately, and the RA measured their height and weight. Participants then completed the Beck Depression Inventory–Second Edition (BDI-II; Beck, Steer, & Brown, 1996) and the Trait form of the State-Trait Anxiety Inventory (STAI; Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983). These measures ensured that, across groups, participants experienced similar levels of depression and general anxiety in their everyday lives and screened individuals who reported experiencing high levels of depression (BDI-II scores of ≥29).

Participants rated their current level of general negative affect three times using the appropriate scale from the Positive and Negative Affect Schedule (PANAS; Watson, Clark, & Tellegen, 1988): at baseline, shortly after entering the research laboratory (PANAS-NA_B); 5 min after the end of the stress or control manipulation (PANAS-NA_1); and 45 min after the manipulation ended (PANAS-NA_2). They completed the NA scale only because intra-subject fluctuations in self-reported stress correlate with fluctuations in negative but not positive affect (Watson et al., 1988).

The RA fitted a Vrije Universiteit Ambulatory Monitoring System (Version 5fs) shortly after the participant's arrival to measure heart rate continuously. After attaching the equipment, the RA waited 5 min before sampling heart rate for 2 min; this sample represented baseline heart rate for each participant (HR_B). The average heart rate during the final 12 min represented heart rate during the manipulation (HR_1). Finally, average heart rate over 5 min, starting at 40 min after the manipulation ended,

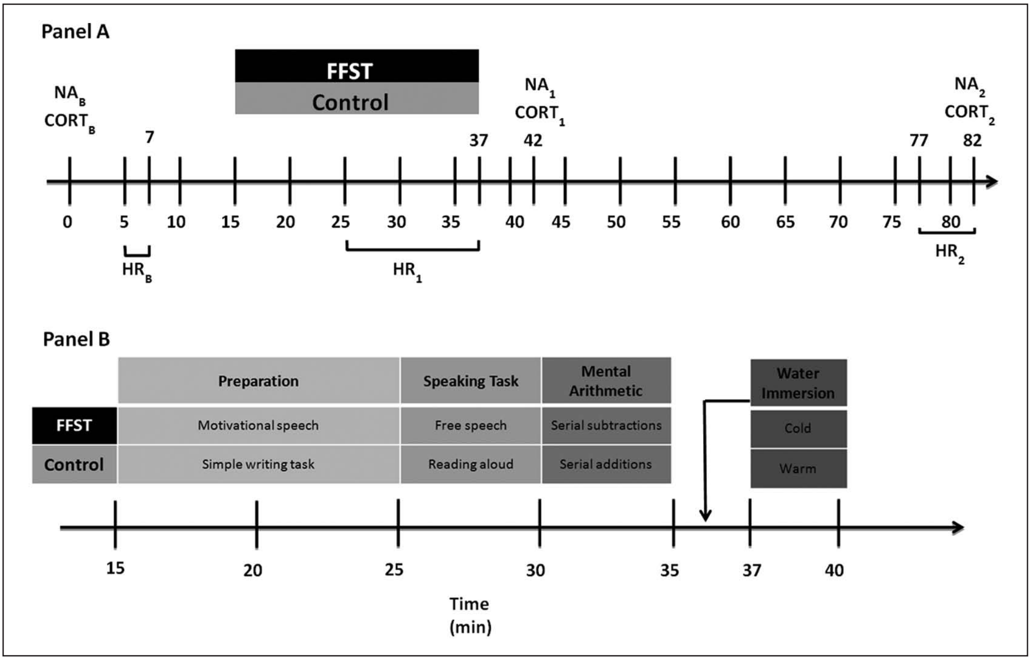

Figure 1. Panel A shows the sequence of experimental events, from the entry of the participant into the laboratory, at Time = 0, to his departure, at Time = 82. NA_B, HR_B, $CORT_B$, NA_1, HR_1, $CORT_1$, NA_2, HR_2, and $CORT_2$ refer to data-sampling events. The experimental manipulation (for both the FFST and Control groups, as indicated by the black and grey bars, respectively) began at Time = 15 and ended at Time = 37. Panel B shows the various components of the experimental manipulation, for each group, in more detail.
FFST: Fear-Factor Stress Test.

represented post-manipulation heart rate (HR_2). The RA removed the device immediately before the participant departed.

The RA collected three saliva samples using SARSTEDT Salivette® Cortisol swabs (SARSTEDT, Nümbrecht, Germany): at baseline, shortly after the participant entered the research laboratory ($CORT_B$); 5 min after the end of the stress or control manipulation ($CORT_1$); and 45 min after the manipulation ended ($CORT_2$). After each collection, the RA immediately placed the cotton swab into an individually labelled tube and stored it in a freezer until transportation to a laboratory for salivary cortisol analyses.

Immediately following data collection, the RA debriefed participants completely, assuring those in the Stress group that no one rated their performance and that no recording occurred. The study then concluded.

Experimental manipulations. Stress-group participants experienced the *Fear-Factor Stress Test* (*FFST*), a stress-induction method described by du Plooy, Thomas, Henry, Human, and Jacobs (2013). This method combines the Trier Social Stress Test (TSST; Kirschbaum et al., 1993) and the Cold Pressor Test (CPT; Hines & Brown, 1932), provoking both ANS and HPA-axis activity. The RA instructed participants to imagine auditioning for the reality television show *Fear Factor* and then read a set of standardised instructions detailing the audition process. The participants completed three tasks: (a) a 5-min free motivational speech describing why they should appear on *Fear*

Factor, (b) a 5-min mental arithmetic task measuring thinking under pressure, and (c) a test of pain resilience measuring tolerance for the show's physical demands. The participants completed the three tasks in front of two judges, who evaluated their suitability for the show.

Participants received a blank sheet of paper and 10 min to prepare the speech. After preparation, the RA took them to a room illuminated by a halogen lamp; this room contained a video camera and a panel of judges. The smartly dressed undergraduate male and female, both unknown to the participant, sat behind a desk and served as judges. Participants received 5 min to present the extemporaneous speech; if they stopped speaking before 5 min elapsed, the female judge delivered standard prompts (e.g., 'You still have time left, please continue' or 'Do you think you have the competitive edge to win Fear Factor?'). Following the speech, participants performed serial subtractions of 17, starting from 2043, for 5 min. If the participant subtracted incorrectly, the female judge instructed him to restart at 2043. Finally, the male judge instructed the participant to submerge, for as long as possible, his dominant arm, up to the elbow, in 0°C–4°C water, for a maximum of 2 min. Participants remained standing for all three tasks; the judges watched them throughout.

Administration of control and stress-induction procedures occurred in the same room. For the Controls, the room was lit normally, had no video camera, and no judges. The RA provided the participant with a blank sheet of paper and instructed him to write a summary of everything he had done on that day. The participant wrote for 10 min. The RA then escorted him to the well-lit room, where she left him to stand and read aloud from a general-interest magazine for 5 min. The RA then re-entered the room and instructed the participant to count upwards from zero in multiples of five. The RA again left the room, allowing participants to perform this task aloud and alone for 5 min. The RA then re-entered and instructed the participant to submerge, for as long as possible, his dominant arm, up to the elbow, in 35°C–37°C water, for a maximum of 2 min. The RA remained in the room but did not directly watch the participant, who remained standing.

ROCF. Performance on the ROCF (Osterrieth, 1944; Rey, 1941) represented visuospatial memory performance, visuoconstruction, and planning abilities (Strauss, Sherman, & Spreen, 2006). The RA administered the ROCF copy trial shortly after taking the HR_B measure. She administered an ROCF recall trial about 35 min after the end of the experimental manipulation, a period during which participants performed a number of verbally based cognitive tasks. ROCF administration followed the Strauss et al. (2006) description of conventional procedures.

Data management and statistical analysis

Due to hardware malfunction, we collected complete, uncorrupted sets of heart rate measures for 25 participants (13 in the Stress, 12 in the Control groups). We report analyses related to heart rate for those limited groups only.

We measured visuospatial information processing using three outcome variables: time to complete the ROCF drawing, accuracy of the drawing, and planning and organisational strategy underlying the drawing. Hence, we used both quantitative (Taylor, 1991) and qualitative (Rey Complex Figure Organizational Strategy Score [RCF-OSS]; Anderson, Anderson, & Garth, 2001) methods to score performance on this task.

The 7-point RCF-OSS scoring system identifies seven levels of conceptual strategies, based on organisation and planning, commonly used when completing the ROCF. The basic level captures no attempt to draw the figure; the drawing is unrecognisable. The second and third levels capture poor and random organisation. At the second level, there is some attempt to draw the figure, and

Table 1. Sample characteristics: descriptive statistics and between-group comparisons (N = 38).

Measure	Group		*t*	*df*	*p*	ESE
	Stress (n = 19)	Control (n = 19)				
Age (years)						
M (*SD*)	20.11 (1.33)	19.89 (1.24)	0.50	36	.62	0.17
Range	18–23	18–23				
BMI[a]						
M (*SD*)	23.59 (2.49)	22.24 (3.37)	1.37	34	.18	0.46
Range	19.30–28.50	16.60–29.20				
BDI-II						
M (*SD*)	10.16 (5.74)	10.42 (6.16)	−0.14	36	.89	−0.04
Range	1–23	0–23				
STAI-Trait						
M (*SD*)	39.53 (10.18)	39.32 (10.19)	0.06	36	.95	0.02
Range	23–64	21–57				

Note. BMI = body mass index; BDI-II = Beck Depression Inventory–Second Edition; STAI = State-Trait Anxiety Inventory; ESE = effect size estimate (in this case, Cohen's *d*). We recruited 40 individuals into the study, but excluded 1 because his BDI-II score exceeded 29 and 1 because he was taking a steroid-based medication.
[a]Data are reported for 36 participants (n = 18 in each group). Due to experimenter error, BMI values were not recorded for 1 Control and 1 Stress participants.

the third has at least one configural element. The fourth level indicates a piecemeal approach. The fifth to seventh levels have the main configural elements drawn early, with the most advanced strategy featuring construction of the main configural elements before other parts of the figure (Anderson et al., 2001). Although the RCF-OSS was designed to capture developmental variability in ROCF copy strategy in children, it 'appears suitable for adults as well' (Lezak, Howieson, & Loring, 2004, p. 547) and bears many of the same formal characteristics of ROCF qualitative scoring systems that are used in adults and that appear to show convergent validity (Knight, 2003; Strauss et al., 2006).

Inter-rater reliability of the 36-point Taylor scoring system is >.90 (Strauss et al., 2006). Inter-rater reliability of the RCF-OSS is estimated at .85 to .92 (Anderson et al., 2001).

We provide details about specific analyses before presentation of their results. We completed all statistical analyses using SPSS version 20.0. We set α at .05, and we provide ESEs for each analysis. In most cases, data distributions met the required assumptions for the relevant inferential statistical analyses; we made necessary adjustments where assumptions were violated (e.g., by using Greenhouse-Geisser degrees of freedom corrections).

Results

Sample characteristics

Independent samples *t*-tests detected no significant between-group differences with regard to age, BMI, BDI-II scores, and STAI-Trait scores (see Table 1). The mean BMI value across the sample (and the mean within each group) fell within the conventional 'normal' range of 19–25; controlling this variable is important because of the positive association between cortisol excretion rate and

Table 2. Measures of stress and cognitive performance: descriptive statistics.

Measure	Sample (*N* = 38)	Group	
		Stress (*n* = 19)	Control (*n* = 19)
PANAS-NA scale			
Baseline	14.08 (4.16)	13.79 (3.85)	14.37 (4.52)
Time 1	14.79 (6.55)	16.26 (7.26)	13.32 (5.55)
Time 2	12.50 (3.11)	12.63 (2.73)	12.37 (3.51)
Heart rate[a]			
Baseline	74.10 (10.17)	73.44 (10.17)	74.83 (10.57)
Time 1	90.54 (16.12)	96.40 (17.99)	84.18 (11.37)
Time 2	73.88 (10.63)	77.06 (12.80)	70.44 (6.55)
Salivary cortisol			
Baseline	7.90 (3.05)	7.71 (2.62)	8.09 (3.50)
Time 1	10.29 (5.46)	13.80 (5.09)	6.77 (3.06)
Time 2[b]	7.48 (2.51)	8.69 (2.35)	6.26 (2.09)
ROCF: copy			
Time[c]	174.47 (62.59)	187.22 (73.49)	161.72 (48.17)
Accuracy	34.36 (1.56)	34.13 (1.85)	34.58 (1.22)
Planning and organisation	5.29 (1.04)	5.11 (1.29)	5.47 (0.70)
ROCF: recall			
Time	135.53 (60.84)	155.28 (68.08)	115.78 (46.47)
Accuracy	20.04 (5.13)	20.55 (6.34)	19.53 (3.64)
Planning and organisation	4.66 (1.10)	4.32 (1.25)	5.00 (0.82)

Note. Means are provided with standard deviations in parentheses. Heart rate was measured in beats per minute. Salivary cortisol was measured in nanomoles per litre. For the ROCF, time to complete the drawing was measured in seconds. PANAS = Positive and Affect Negative Affect Schedule; ROCF = Rey-Osterrieth Complex Figure Test.
[a]Values reported are for *n* = 13 in the Stress group and *n* = 12 in the Control group.
[b]Data are reported for 36 participants (*n* = 18 in each group). Due to experimenter error, salivary cortisol samples were not collected for 1 Control and 1 Stress participants.
[c]Data are reported for 36 participants (*n* = 18 in each group). Due to experimenter error, time to complete the copy was not recorded for 1 Control and 1 Stress participants.

BMI, particularly in obese individuals (Fraser et al., 1999). The mean value of the BDI-II scores fell with the range conventionally described as ‘minimally depressed’ (0–13) for both groups. The STAI-Trait scores, compared to the normative data for male college students ($M = 38.30$, $SD = 9.18$) supplied by the test manual (Spielberger et al., 1983), appeared representative of the general population ($p = .50$).

Experimental manipulation check

Table 2 presents descriptive statistics for self-report and physiological measures of stress. The analyses determined that, with regard to those measures, (a) participant scores were, regardless of subsequent group assignment, comparable before the experimental manipulation, and (b) the stress and control manipulations affected the groups differentially.

Separate independent-samples *t*-tests confirmed that, at baseline, there were no detectable between-group differences in terms of PANAS-NA scores, $t(36) = -0.43$, $p = .67$, $d = 0.14$, heart rate, $t(24) = -0.15$, $p = .89$, $d = 0.06$, or salivary cortisol, $t(36) = -0.38$, $p = .71$, $d = 0.12$.

A mixed-design analysis of variance (ANOVA) examining the PANAS-NA data detected a significant within-subjects main effect of Testing Stage, $F(2, 35) = 5.38$, $p = .01$, partial $\eta^2 = .13$, and a significant Group × Testing Stage interaction effect, $F(2, 35) = 3.32$, $p = .04$, partial $\eta^2 = .08$. There was no detectable between-groups main effect, $F(1, 36) = 0.44$, $p = .51$, partial $\eta^2 = .01$ (Stress group: $M = 14.23$, $SE = 0.94$; Control group: $M = 13.35$, $SE = 0.94$).

A mixed-design ANOVA examining the heart rate data detected a significant within-subjects main effect of Testing Stage, $F(1.55, 35.68) = 68.46$, $p < .001$, partial $\eta^2 = .75$, and a significant Group × Testing Stage interaction effect, $F(1.55, 35.68) = 8.97$, $p = .002$, partial $\eta^2 = .28$. There was no detectable between-groups main effect, $F(1, 23) = 1.67$, $p = .21$, partial $\eta^2 = .07$ (Stress group: $M = 82.30$, $SE = 3.12$; Control group: $M = 76.48$, $SE = 3.25$).

A mixed-design ANOVA examining the salivary cortisol data detected a significant within-subjects main effect of Testing Stage, $F(2, 68) = 22.23$, $p < .001$, partial $\eta^2 = .40$, a significant Group × Testing Stage interaction effect, $F(2, 68) = 33.06$, $p < .001$, partial $\eta^2 = .49$, and a significant between-groups main effect, $F(1, 34) = 9.21$, $p = .005$, partial $\eta^2 = .21$ (Stress group: $M = 10.08$, $SE = 0.69$; Control group: $M = 7.13$, $SE = 0.69$).

Separate paired-samples *t*-tests did not detect differences in Stress-group self-reported or physiological measures of stress at the beginning and end of the experimental sessions. Specifically, PANAS-NA_B and PANAS-NA_2, HR_B and HR_2, and $CORT_B$ and $CORT_2$ scores did not differ significantly, $t(18) = 1.38$, $p = .18$, $d = 0.49$; $t(12) = -1.70$, $p = .12$, $d = 0.30$; and $t(17) = -1.60$, $p = .13$, $d = 0.39$, respectively.

ROCF copy and delayed recall trials

Two independent raters, blind to group assignment, scored the ROCFs. Inter-rater reliability was $r = .99$ for the quantitative (accuracy) and $r = .89$ for the qualitative (planning and organisation) scores. Where between-rater discrepancies occurred, the research team met to reach consensus about the value entered into final database.

Table 2 presents descriptive statistics for performance on the two trials. There were no detectable between-group differences in performance on the copy trial: For time to complete the copy, $t(34) = 1.23$, $p = .23$, $d = 0.40$, accuracy of the copy, $t(36) = -0.88$, $p = .39$, $d = 0.29$, or planning and organisation of the copy, $t(36) = -1.10$, $p = .28$, $d = 0.35$.

We created three separate general linear models (GLMs), with interactions, to describe the influence of self-report and physiological measures of stress, as well as ROCF copy performance, on ROCF delayed recall performance. The model-creation process involved testing alternative hypotheses using nested model comparisons, and eventually generating, for each of the three ROCF outcome variables (time to complete the delayed recall trial, accuracy of the figure at delayed recall, and planning and organisation of the figure at delayed recall), the best-fitting model that explained a significant amount of the variance. Specifically, we removed one variable at a time, in order of decreasing complexity (i.e., we removed three-way interactions before two-way interactions), to make the parameter estimates more efficient.

Figure 2 shows the results of these analyses. The box-and-whisker plot in Panel A shows the relationship between the predictor variable group status and the outcome variable time to complete the delayed recall trial. Although this relationship tended towards statistical significance, $t(34) = 2.76$, $p = .050$, the model based on it was not the best-fitting one for the data. Instead, the most significant predictor of ROCF recall time was ROCF copy time, $r = .58$, $p < .001$. Hence, the scatterplot in Panel B shows the relationship between that predictor (time taken to complete the figure copy) and the outcome (time taken to complete the figure recall). Panel C illustrates the final model

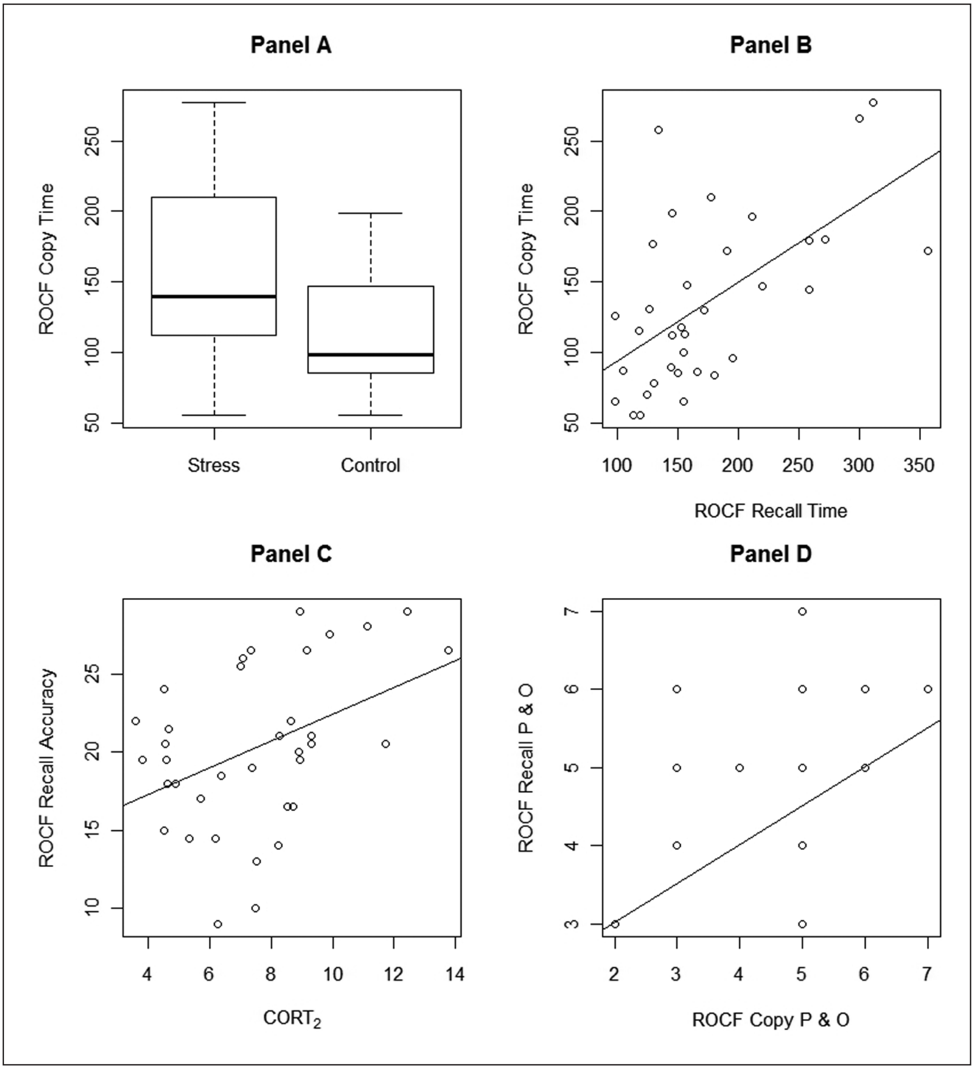

Figure 2. Visual representations of the results of four analyses arrived at via a theoretically guided exploratory procedure using general linear models predicting (a) time to complete the ROCF delayed recall trial (Panels A and B); (b) accuracy of the figure at delayed recall (Panel C); and (c) planning and organisation of the figure at delayed recall (Panel D). Each scatterplot presents the line of best fit.
ROCF: Rey-Osterrieth Complex Figure Test; P & O: planning and organisation.

for the second GLM. The only significant predictor of ROCF recall accuracy was $CORT_2$, β = .32, $r = .34$, $p = .036$. Hence, the scatterplot shows the relationship between the predictor ($CORT_2$ values) and the outcome (ROCF recall accuracy). Panel D illustrates the final model for the third GLM. The only significant predictor of ROCF recall planning and organisation was ROCF copy planning and organisation, β = .52, $r = .47$, $p = .003$. Hence, the scatterplot shows the relationship between the predictor (planning and organisation of the figure copy) and the outcome (planning and organisation of the figure at delayed recall).

Discussion

We investigated the effects of acute psychosocial stress on visuospatial memory, planning, and organisation in healthy males. We hypothesised that participants exposed to an acute psychosocial stressor will, relative to those exposed to a non-stressful control condition, (a) require more time to complete the ROCF recall trial, (b) create less accurate reproductions on that recall trial, and (c) show poorer planning and less gestalt-based organisational strategies while creating that reproduction.

Converging data from the self-report measure, the cardiovascular measure (representing ANS functioning), and the salivary cortisol measure (representing HPA-axis functioning) indicate that the experimental manipulation worked as intended. We induced a stress response in Stress-group participants, while reducing markers of stress in Control-group participants. Of particular importance for this research is that the FFST increased cortisol levels significantly: Once this hormone crosses the blood–brain barrier and occupies glucocorticoid receptors at higher rates than normal, it affects brain regions critical to memory and other cognitive processes (Alderson & Novack, 2002).

Regarding performance on the ROCF copy trial, there were no detectable between-group differences in time to complete the trial, accuracy of the copied figure, or planning and organisation of the copied figure. Hence, we can infer that participants in the Stress and Control groups were sampled from the same population and that, before the experimental manipulation, there were no detectable individual differences in their ability to encode and reproduce the complex figure.

The observed data did not confirm our prediction that Stress-group participants would take more time to complete the delayed recall trial than Control-group participants. The only significant predictor of time taken to complete the ROCF delayed recall trial was time taken to complete the copy trial. Group membership, when taken alone, showed a relatively weak relationship with recall time; this relationship disappeared, however, when we added copy time to the model. This order of effects probably reflects sampling error: As Table 2 shows, Control-group participants took, on average, about 25 s fewer to complete their copies. Those individual differences obviously cannot be attributed to the stress induction or to circulating cortisol: The copy trial took place before the experimental manipulation. Hence, the mean between-group difference in time to complete the delayed recall trial may be a continuation of the difference that existed at copy, rather than a difference that emerged post-manipulation. The GLM suggests that this interpretation is accurate.

The observed data disconfirmed our prediction that participants exposed to the stress condition would reproduce the complex figure less accurately on the delayed recall trial. Analysis of data from the 36-point quantitative scoring system (Taylor, 1991) indicated that the only significant predictor of accuracy on that trial was level of circulating cortisol and that the result was in the direction opposite to that predicted: Higher levels were associated with better performance.

This result is inconsistent with some studies reporting impaired visuospatial memory performance after exposure to stress (Morgan et al., 2006; Taverniers et al., 2010). One way to reconcile our results with those is to note that the relation between cortisol levels and declarative memory function takes an inverted U-shaped function: Too much *and* too little cortisol disrupts declarative memory functioning, whereas moderate levels enhance such functioning (Andreano & Cahill, 2006). Morgan et al. (2006) and Taverniers et al. (2010) used Special Forces army training to provoke high-intensity stress and consequent increases in cortisol levels larger than those provoked by laboratory-based procedures (Het, Ramlow, & Wolf, 2005). Therefore, it is possible that, because those studies examined the effects of stress on memory at the extreme right of the inverted U, their data (associated with large cortisol increases) might be expected to show impairing effects, whereas ours (associated with moderate cortisol increases) might not.

If this interpretation based on cortisol's inverted U-shaped function is accurate, then our data should be consistent with those from studies that use laboratory-based acute psychosocial stressors (i.e., stressors that might induce moderate increases in cortisol levels): For example, Hoffman and al'Absi (2004) reported no changes in ROCF performance following exposure to a TSST-like procedure, and Luethi et al. (2009) reported enhanced visuospatial memory performance after TSST exposure.

Finally, the observed data disconfirmed our prediction that participants exposed to the stress condition would show poorer planning and fewer gestalt-based organisational strategies in creating their reproduction on the ROCF delayed recall trial. Analysis of data from the RCF-OSS 7-point qualitative scoring system (Anderson et al., 2001) indicated that the only significant predictor of planning and organisation on the ROCF delayed recall trial was the approach to planning and organisation taken on the copy trial. In other words, those who planned and organised their figure copies better also planned and organised their recalled figures better, and stress did not modify the relative efficiency of approaches to the recall task. This finding stands in contrast to that of Morgan et al. (2006), who reported that their participants took a narrow and detailed (i.e., piecemeal, rather than gestalt-based) approach to their construction of the figure. As before, the contrasting patterns of data suggest that intense stress (as induced by Morgan et al.), but not moderate stress (as induced in this study), might have an impairing effect on planning and organisation of visuospatial information.

Our finding regarding intact planning and organisation of visuospatial information following stress exposure also stands in contrast to results of other studies investigating the effects of laboratory-based stress induction on PFC-related functions, such as working memory and decision-making (e.g., Schoofs et al., 2008; van den Bos et al., 2009). However, none of those studies undertook specific examination of the planning and organisation of visuospatial information. Hence, it is possible that working memory and decision-making tap into different executive functioning processes than planning and organisation of visuospatial information (MacDonald, Cohen, Stenger, & Carter, 2000; Tekin & Cummings, 2002) and that, therefore, there are differential effects of stress on these cognitive processes.

We note two limitations of the present study. First, following previous stress research (e.g., Luethi et al., 2009; Morgan et al., 2006; Taverniers et al., 2010) and because of concerns about sex differences in cortisol response (Kirschbaum et al., 1995, 1999), we intentionally sampled only men. Second, and again following previous stress research (e.g., Schoofs et al., 2008; Thomas, Laurance, Nadel, & Jacobs, 2010; van den Bos et al., 2009), we used only one measure of cognitive performance. From a methodological perspective, this strategy is not ideal (Campbell & Fiske, 1959). Given the present demonstration that exposure to the FFST enhances accuracy of ROCF performance on the delayed recall trial, future research might do well to explore whether, in both men and women, these enhancing effects generalise to multiple measures of the construct.

Summary and conclusion

The present data indicated that exposure to an acute psychosocial stressor enhanced visuospatial memory performance in healthy males. This finding is important because performance in this cognitive domain underpins effective spatial learning, memory, and, most crucially, navigation. Many individuals in South Africa and other low- and middle-income countries encounter stressful settings and contextual challenges regularly while learning, memorising, and navigating through environmental space. The importance of the current research is that it reinforces the notion that moderate levels of stress do not compromise the human ability to conquer these challenges and to adapt to novel environments.

Funding

The South African National Research Foundation (NRF) supported this research.

Note

1. A stressor is an event that threatens major adaptive goals, thereby jeopardising the physical and/or psychological well-being of an individual (Kemeny, 2003).

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