Acute stress, memory, attention and cortisol

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Abstract

An investigation was conducted to explore the relationship between acute changes in cortisol and memory and attention in the context of an acute naturalistic stressor, namely, examination stress. Sixty students (36 male, 24 female) participated in an assessment of self-reported levels of stress, salivary cortisol, short term memory, selective and divided attention and auditory verbal working memory. Assessments were conducted during a non-exam and exam period. The results revealed that the exam period was associated with an increase in perceived levels of stress, but also a significant reduction in levels of salivary cortisol, compared with the non-exam period. This reduction in cortisol was associated with enhanced short-term memory (as measured by the total number of words recalled in a free recall task), impaired attention and an impairment in the primacy effect (a hippocampal-specific index of short term memory), but no significant effects on auditory verbal working memory. It was concluded that the results support the view that cortisol can modulate cognitive processes and that the effects of corticosteroids on cognitive function are selective. © 2000 Elsevier Science Ltd. All rights reserved.

Keywords: Cortisol; Cognition; Acute Stress; Attention; Memory; Examinations

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1. Introduction

There are now a myriad of research avenues under exploration in the quest to better understand the causes and consequences of psychological stress. Among the most compelling areas of enquiry, is the literature devoted to the effects of stress and concomitant stress hormones on cognitive performance. This work has taken many forms, but in the main has chosen to explore the effects of acute/experimentally induced alterations (i.e., stress-induced or pharmacologically-induced) or chronic/naturally occurring alterations (i.e., age or disease associated alterations) in glucocorticoids on a variety of cognitive parameters.

With regard to the former, the oft-cited observation is that acute increases in corticosteroid levels are associated with cognitive decrements in both attention and memory. For example, Newcomer et al. (1994) conducted a study with a group of healthy human subjects (n=19) who were divided into a dexamethasone or placebo treatment group. The individuals in each group did not differ in terms of their age (dexamethasone group=38.3 years vs. placebo group 29.4 years) or years of education (dexamethasone group=16.5 years vs. placebo group 15.9 years). Their results revealed that the administration of dexamethasone over a four day period was associated with impaired declarative memory up to four days after treatment, but there were no effects on a task of divided attention. In a later study Newcomer et al. (1999) extended this work in a comparison of the effects of a low oral dose of cortisol (to approximate mild stress), a high oral dose of cortisol (to approximate major stress) and placebo in healthy matched subjects (n=51). After a treatment period of four days, a significant but reversible decrease in verbal declarative memory was observed in participants receiving the high dose of cortisol. No significant changes in non-verbal memory, sustained or selective attention, or executive function were observed.

Similarly, in a within-subjects investigation also with healthy human subjects (n=24), Bohnen et al. (1990) observed that subjects who exhibited high cortisol levels during a session of continuous mental tasks had poorer divided attention following task performance, compared with their divided attention following a control session. However, they identified no effects of cortisol on a task of verbal memory. Kirschbaum et al. (1996) also examined the effects of cortisol on memory produced in response to an acute experimental stressor, i.e., the Trier Social Stress Test. They found that participants with higher cortisol responses showed poorer verbal recall. They also observed that mean cortisol levels were significantly lower five minutes before the commencement of the stressor, thus, highlighting the differential effects during anticipation of a stressor versus those evident following the experience of the stressor.

The literature pertaining to the effects of chronic/naturally occurring alterations in corticosteroids are consistent with these observations. For example, a number of investigators have assessed cognitive performance in patient groups known to exhibit hypercortisolemia, such as patients with depression or Cushing’s disease (Rubinow et al., 1984; Starkman et al., 1992; Mauri et al., 1993). This work has served only to reiterate the view that increases in corticosteroids are related to poorer cognitive
function. This is also true of the research that has been conducted with elderly cohorts. Notwithstanding individual differences in neuroendocrine function, the elderly are characterised by relatively stable levels of cortisol (Sherman et al., 1985; Waltman et al., 1991), but a decrease in dehydroepiandrosterone (DHEA) and its sulfate (DHEAS), the body’s natural cortisol antagonist (Svec and Lopez, 1989; Ebing and Koivisto, 1994; Svec, 1997). Thus, it has been speculated that the elderly are at particular risk from corticosteroid-related cognitive impairment because the apparently protective effects of DHEA and DHEAS are reduced (Carlson and Sherwin, 1998). The implications of this are clearly far-reaching at a time when most developed societies are increasingly characterised by ageing populations. Thus, a great deal of research effort has been expended into delineating the role of corticosteroids in cognitive function in the elderly. For example, Lupien and colleagues conducted a study with “healthy” elderly individuals on whom they collected data on cortisol levels over a four year period (Lupien et al., 1994). Individuals who exhibited increasing cortisol levels over the four years, and also had high levels at the time of assessment, had significantly poorer performance on tasks of selective attention and explicit memory than participants whose levels of cortisol declined over the four years; and patients whose levels increased over four years, but were moderate at the time of assessment.

Seeman et al. (1997) reported similar results from the subsample of women in their cohort of elderly individuals (aged 70–79 years). The women in this cohort exhibited an inverse relationship between urinary cortisol and memory performance at baseline. Furthermore, those women with increased cortisol levels over a 2.5 year period were more likely to exhibit declines in memory performance. No relationships between cortisol and memory were evident in the men. Indeed, this pattern of results has been repeated in a more recent study, also with an elderly cohort, in which cognitive changes over a 1.9 year period were again predicted by levels of cortisol at baseline (Kalmijn et al., 1998).

We have offered only a cursory overview of this now extensive literature, however, investigators have drawn a number of conclusions based on the available data. Firstly, it is evident that both endogenous and exogenous based increases in glucocorticoids are associated with deficits in both memory and attention (Reus et al., 1985; Lupien and Forget, 1995). Secondly, evidence that glucocorticoids can compromise the functioning of the hippocampus (Meaney et al., 1995), has led investigators to speculate that hippocampal-based cognitive functions may be at particular risk from the deleterious effects of glucocorticoids (Lupien and Forget, 1995; Wolkowitz et al., 1997). Finally, in their review of the human and animal literature on the acute effects of glucocorticoids, Lupien and McEwen (1997) concluded that an inverted U-shaped relationship is evident between glucocorticoids and the nature and magnitude of cognitive dysfunction.

In the present study, we have attempted to further existing knowledge on the effects of glucocorticoids on cognitive function. The indices of memory and attention selected for investigation were guided by previous research. In particular, we adopted indices which have previously been shown to be affected by acute changes in corticosteroids, including verbal memory (Bremner et al., 1995), selective attention (Lupien
et al., 1994) and divided attention (Bohnen et al., 1990). In addition, we selected memory indices which have previously been reported to significantly activate the prefrontal cortex in neuroimaging studies, i.e., verbal working memory (Smith et al., 1998), and sources of attention which are influenced by corticosteroid levels during the memory process (De Kloet et al., 1998). Much of this previous research into the effects of acute changes in corticosteroids has, however, been largely experimental in nature (e.g., laboratory stress paradigms: Bohnen et al., 1990; pharmacologically-induced changes: Newcomer et al., 1994). Thus, the aim of this investigation was to examine whether acute changes in corticosteroids during an acute and naturalistic stressor, namely examinations, also modulate cognition.

2. Methods

2.1. Participants

Undergraduate and postgraduate students who were known to have a period of examinations within the second term of the English academic year (i.e., January to March) were approached regarding the study. Posters advertising the study were displayed in relevant departments and, where possible, a short presentation regarding the research project was made during scheduled lectures. Participation in the project was entirely voluntary. Only psychology undergraduates were able to claim “course credits” for participation in the study. These credits were, however, claimed for participation in research per se and were not linked exclusively to participation in the present study.

The resultant sample consisted of 60 students with a mean age of 22 years (±4.5 years). There were 36 male participants and 24 female participants, all of whom were due to embark upon an examination period within six months of enrolment into the study. Time of menstrual cycle was not controlled in the female participants. A student population were selected for this investigation not only because they provided a vehicle for exploring the effects of a naturally-occurring acute stressor (i.e., examinations), but also because they were expected to be relatively homogenous in terms of intellectual ability. Thus, the potential for task performance to be confounded by intelligence was minimised. The investigation was conducted with the adequate understanding and written consent of all participants.

2.2. Materials

2.2.1. Self reported levels of stress

Self reported levels of stress were assessed once during the non-exam period and once during the exam period using the global measure of perceived stress (Cohen et al., 1983). This scale asks respondents to reflect on symptoms of stress they may have experienced in the previous month. The reported Cronbach alpha coefficients for this scale range from 0.84 to 0.86 and the scale has been found to correlate with
life events scores and measures of depressive symptomology and social anxiety stress (Cohen et al., 1983).

2.2.2. Salivary cortisol

All participants were asked to provide five saliva samples over two consecutive days during both the non-exam and exam periods. The samples were collected using salivettes and were used to determine levels of cortisol. Salivary cortisol has been shown to correlate well with plasma cortisol (Shimada et al., 1995). In addition, the assessment of cortisol in saliva avoids the confounding effects of venepuncture-induced stress. Cortisol also remains stable in saliva for several days and so is ideally suited to paradigms in which the participant is required to provide multiple samples away from the study site and often several days before follow-up (Kahn et al., 1988). Participants were asked to provide samples between: 0700–0800 h; 60 min after the first sample; 1200–1300 h; 1600–1700 h and 2300–2400 h; to avoid meals within 60 min of providing each sample and to avoid caffeine-containing products during the two days of sampling. These sampling times and dietary restrictions were designed to control for the confounding effects of food and caffeine intake, whilst also controlling for diurnal variations in cortisol. Participants were asked to keep their samples refrigerated until their follow-up appointment when they were sent to the laboratory for analysis.

The salivary cortisol assays were conducted by Diagnostech. Levels of cortisol were determined by using a modification of the Cortisol Elisa Kit (Neogen Corporation, KY, USA). To accommodate the levels of cortisol present in the saliva, each sample was diluted (using the cortisol standard provided with the kit) to give calibrators in the range 0.72–69 nM. Three control samples were also included in each assay (5 nM, 15 nM and 30 nM). Assays were conducted in several batches during the 5 months of data collection. The sensitivity of the assays is 0.3 nM and the intra and inter-assay coefficients of variation are 6.8% and 9.2% respectively.

Fifty microliters (μl) of saliva was added to the appropriate wells in the anti-cortisol rabbit antibody precoated microplate. To each well, 50 μl of the cortisol horseradish peroxidase conjugate was also added, with the exception of the substrate blanks. The plate was then incubated for 1 h at room temperature and then washed three times with buffer. One hundred and fifty μl of 3,3’,5,5’ Tetramethylbenzidine (TMB) was added to the wells. The plate was then incubated at room temperature for 30 min to allow the colour to develop; this reaction was stopped by the addition of 50 μl 0.5 M HCl. Each plate was read at 450 nm with an MRX Microplate Reader (Dynex Technologies, Germany). The cortisol concentrations were determined from a calibration curve.

2.2.3. Cognitive assessment

Consistent with previous work in this area, indices of memory and attention were assessed. With regard to the former, a free recall task was used to assess short term memory. This test has been described elsewhere (Smith et al., 1995). However, briefly: a standardised list of twenty words that controlled for word length and frequency was presented to participants. Immediately following presentation, parti-
Participants were asked to recall as many words as possible. In order to minimise practice effects, words were presented in a random order during the second (exam) assessment period. The results for this test are expressed as the total number of words recalled correctly (i.e., scores ranged from 0–20).

The remaining tests of memory and attention were taken from the Test of Everyday Attention (TEA: Robertson et al., 1994): elevator counting with reversal task (a measure of auditory verbal working memory); telephone search task (a measure of selective attention) and telephone search while counting (a measure of divided attention). These tasks have been described in detail elsewhere (Robertson et al., 1994). Briefly, the elevator counting with reversal task required participants to attend to a series of tones presented on an audio-tape. Participants were informed that they would hear three types of tones: a low pitched tone which indicates that the elevator has stopped and when it resumes it will be travelling in a downward direction; a high-pitched tone which indicates that the elevator has stopped and when it resumes it will be travelling in an upward direction; and middle-pitched tones which indicate the number of floors the elevator has travelled (one tone is generated per floor). The participant was required to keep track of the floors to which the elevator has travelled by counting the number of middle-pitched tones (each middle-pitched tone indicated one floor), whilst vocalising each change of direction (e.g., in the presence of a high-pitched tone, subject must say “up”) and also altering the direction of floor-counting according to whether a high-pitched or low-pitched sound had been displayed. For example, the following sequence <tone, tone, high-tone, tone, tone, low-tone, tone, tone> would correspond to the following vocalisation <1, 2, “up”, 3, 4, “down”, 3, 2> and the response that the elevator had stopped at the second floor. The results for this test are expressed as the total number of correct answers out of 10 trials (i.e., raw scores ranged from 0–10; scaled scored from 2–18).

The telephone search task required participants to identify entries in a telephone directory. Two symbols appeared beside each entry, however, the participant was required to identify only those entries which appeared with a pair of identical symbols (e.g., two stars, two squares etc.). This task was scored by summing the total number of correctly identified pairs and dividing by the total time taken. Thus, the results for this test are expressed as the time taken to correctly identify each target (i.e., time per target, expressed in seconds).

Finally, the telephone search while counting task required the participant to perform a second telephone search task (as described above) while counting a string of tones presented on a tape recorder. Participants were asked to expend equal effort in performing both aspects of the task. The score for this task was derived from the score obtained from both this and the telephone search task, such that the final score reflected the extent to which performance was impaired through dual task performance. The results for this test are, therefore, expressed as the additional time taken to correctly identify each target (expressed in seconds).

For all the cognitive tasks, participants were asked to work as quickly and accurately as possible. Task performance was randomised throughout the day during both the exam and non-exam periods so that the effects of diurnal variations in cortisol on cognitive performance would be distributed evenly between the two conditions.
For all the tasks performed from the TEA, participants engaged in several practice trials before each task to ensure that they had understood the instructions, were able to perform the task and to reduce the effects of anticipatory stress during the first (non-exam) condition. Finally, as per the authors’ recommendations, raw scores on the TEA tasks were converted into scaled scores to take into account the age of participants. For a detailed explication of the scoring formulae and tables of scaled scores the reader is directed to the test manual (Robertson et al., 1994). Finally, different versions of each of the attention tasks were used during the non-exam and exam assessments in order to control for practice effects.

2.3. Procedure

All subjects participated in an assessment of self-reported levels of stress, salivary cortisol and cognitive function on two occasions: a period during which no University examinations were scheduled (non-exam — in a period between October and December) and the two week period immediately preceding the start of an examination period (exam — in a period between January and February). For all participants, the non-exam period occurred before the exam period. Prior to the non-exam period, participants were allocated ten salivettes and were asked to provide five saliva samples per day, over two consecutive days, at the allotted times and to adhere, as far as possible, to the dietary instructions. In addition, subjects were asked, where possible, to collect these samples in the two days immediately prior to their follow-up. At follow-up, each subject returned the salivettes; was asked to confirm that they had complied with the timing and dietary requirements of the samples; completed the stress scale (Cohen et al., 1983) and then completed the four tasks of memory and attention. In order to control for task-order effects, the order of task presentation was counterbalanced using a Latin square design (see Table 1). Subjects were randomly allocated to one of four task orders (A–D), such that a subject allocated to order A performed the short-term memory task first, followed by the elevator counting with reversal, telephone search and telephone search while counting tasks etc., as shown in Table 1. Furthermore, task order during the non-exam condition determined task order during the exam condition. Specifically: individuals in task order A during the non-exam period were allocated to task order B during the exam period;

<table>
<thead>
<tr>
<th>Task Order</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
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<tbody>
<tr>
<td>A</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>B</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>C</td>
<td>3</td>
<td>4</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>D</td>
<td>4</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

*a 1=short-term memory task; 2=elevator counting with reversal task; 3=telephone search task; 4=telephone search while counting task.*
individuals in task order B during the non-exam period were allocated to task order C; individuals in task order C during the non-exam period were allocated to task order D during the exam period; individuals in task order D during the non-exam period were allocated to task order A during the exam period.

The non-exam condition ended following completion of the cognitive tasks. All participants were then recalled to participate in the exam condition. This occurred approximately 2–5 months after the non-exam condition. The procedure for the exam condition was identical to that described for the non-exam condition with the exception of the alterations to task-order presentation described above.

3. Results

3.1. Subjective levels of stress

Responses to the perceived stress scale were analysed to determine whether self-reported levels of stress were significantly different between the non-exam and exam periods. The results from a paired samples \( t \)-test revealed that stress scores were significantly higher during the exam period than the non-exam period \( (t=-2.756, p=0.008) \). This is evident from Fig. 1. Indeed, the observed values were marginally higher than the normative values reported for this scale.

3.2. Salivary cortisol

A repeated measures within-subjects analysis of variance was conducted to explore whether levels of cortisol in saliva differed within subjects between the exam and

![Graph showing stress scores](image)

Fig. 1. Difference between exam and non-exam period: \( t=-2.756, P=0.008 \).

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1 Previous research has indicated that gender and age may influence cortisol levels. Thus, these variables were entered as covariates in this analysis, but neither emerged as significant (gender: \( F=2.811, P=0.112 \); age: \( F=1.279, P=0.274 \)) and so these results and the interaction terms are not presented.
Table 2
Repeated measures analysis of variance to examine differences in cortisol levels between: exam and non-exam periods; two sampling days and sampling times

<table>
<thead>
<tr>
<th>Variable</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exam/non-exam</td>
<td>5.164</td>
<td>0.036</td>
</tr>
<tr>
<td>Day</td>
<td>0.000</td>
<td>0.997</td>
</tr>
<tr>
<td>Time</td>
<td>3.128</td>
<td>0.020</td>
</tr>
<tr>
<td>Exam/non-exam × Day</td>
<td>1.013</td>
<td>0.328</td>
</tr>
<tr>
<td>Exam/non-exam × Time</td>
<td>1.067</td>
<td>0.380</td>
</tr>
<tr>
<td>Day × Time</td>
<td>0.582</td>
<td>0.677</td>
</tr>
<tr>
<td>Exam/non-exam × Day × Time</td>
<td>0.912</td>
<td>0.462</td>
</tr>
</tbody>
</table>

non-exam period (exam/non-exam); between the two sampling days (day) and across the five sampling times (time). The results (see Table 2) revealed that levels of cortisol did differ between the exam and non-exam period and also across time. However, there were no significant interactions, or effects of day.

The mean (and SE) levels of cortisol for each sampling time on both days of the non-exam and exam conditions are presented in Fig. 2. It is clear from this figure that, although there was evidence of the expected decline in cortisol levels during each of the sampling days, levels of cortisol were significantly and consistently higher during the non-exam period compared with the exam period. Indeed, the observed levels during the exam period corresponded closely with normative levels on the assay, but were consistently higher than normative levels during the non-exam period.

In order to examine the possible confounding effects of individual differences in responses to examination stress, a series of post-hoc analyses were conducted in

![Fig. 2. Difference between exam and non-exam period: F=5.164, P=0.036.](image-url)
which participants were divided into high or low stress groups based on their scores on the stress scale (median split). The data revealed, however, that no significant differences were evident in levels of cortisol between the non-exam and exam periods (data not shown).

3.3. Cognitive performance

A series of paired sample $t$–tests were conducted to explore whether performance on any of the selected tasks of memory and attention differed significantly between the non-exam and exam periods. The significance level for these tests was adjusted to 99% to avoid the possibility of a Type 1 error due to multiple comparisons. The results revealed that, during the exam period, performance on the short-term memory task improved significantly ($t = -2.792; P = 0.007$; see Fig. 3). However, performance on the telephone search task (a measure of selective attention: $t = -4.130; P < 0.0001$) and the telephone search while counting task (a measure of divided attention: $t = -2.175; P = 0.034$) deteriorated significantly during the same period. Performance on the elevator task with reversal (a measure of auditory-verbal working memory) did not differ significantly between the exam and non-exam period ($t = -1.200; P = 0.236$).

Further post-hoc comparisons were conducted on the data from the free recall task to distinguish between the total number of items recalled and the primacy effect. The primacy effect is a measure of consolidation and, therefore, more clearly associated with the memory function of the hippocampus (e.g., Kesner and Novak, 1982). The primacy effect was measured by calculating the frequency with which the first

![Fig. 3.](image-url)
four words presented in the test list appeared in the first eight items recalled. Accordingly, the scores for each participant ranged from 0 to 1 (i.e., 0=none of the initial items were recalled; 0.25=1 of the first four items was recalled; 0.5=2 of the first four items was recalled; 0.75=3 of the first four items was recalled and 1=all four items were recalled). In the non-exam condition the average score was 0.56, and in the exam condition the average score was 0.36. The results from a paired samples \( t \)-test revealed that the difference between the two conditions was significant (\( t=3.644; P=0.001 \)).

Finally, delta scores were calculated from the data on the cognitive indices and the cortisol AUC values obtained during the non-exam and exam periods. Pearson’s correlations were then calculated between the cortisol and cognitive indices’ delta scores. However, none of these correlations were found to be significant at the \( P<0.05 \) level (data not shown).

### 4. Discussion

The present study was designed to examine whether the presence of an acute and naturalistic stressor, i.e., examinations, was associated with changes in perceived levels of stress and related changes in levels of salivary cortisol and performance on indices of memory and attention. As expected, our data revealed that the examination period was associated with a significant increase in self-reported levels of stress. However, the expected concomitant increase in cortisol levels was not observed. Indeed, levels of salivary cortisol were found to be significantly lower during the exam period. Consistent with this reduction in cortisol levels, we observed a significant improvement in the short-term memory task. However, paradoxically, significant decrements were observed in the tasks measuring selective and divided attention and in the primacy effect. No significant differences were observed on the task measuring auditory verbal working memory.

Before exploring the results obtained from the cognitive data, it is important to explore first the apparent discrepancy between the self-reported levels of stress and cortisol. Cortisol is widely regarded as an objective marker of changes in psychological stress (Kirschbaum et al., 1995) and has been shown to increase during periods of both acute (Al’Absi et al., 1997) and chronic (Vedhara et al., 1999) stress. The inverse relationship between perceived levels of stress and cortisol levels in this study is, therefore, perplexing. There is some evidence in the literature of a disassociation between self-reported levels of stress and cortisol when the acute challenge is examinations (Glaser et al., 1994; Malarkey et al., 1995), however, to our knowledge, an inverse relationship has not been reported previously. Detailed enquiry into the factors that give rise to this disassociation or inverse relationship is clearly beyond the scope of the data collected in this investigation. However, it would appear reasonable to speculate that confounding factors may include: seasonal variations in cortisol levels; the activity of other stress hormones (e.g., adrenalin, noradrenalin); the unique nature of examination stress (i.e., a predictable and often recurring stressor); characteristics of the target population (i.e., students) or participants’ appraisal processes.
With regard to the former, although the evidence is equivocal (e.g., Maes et al., 1997; Van Dongen et al., 1998), there have been data suggesting that cortisol levels are higher during winter months compared with summer months (Maes et al., 1997). It is not clear whether the interval between our non-exam and exam sampling periods may have been influenced by such seasonal variations, but this factor may have contributed to the lower levels of cortisol evident during the exam period.

Similarly, with regard to the influence of appraisal processes, one investigation which demonstrated a disassociation between cortisol and perceived stress during an examination period, also observed that a positive association was apparent when subjects were divided according to their perceived levels of stress (i.e., subjects who reported the highest levels of stress also displayed significant increases in cortisol: Malarkey et al., 1995). The authors concluded that these results reflected the importance of the individual’s appraisal of the event in determining the event’s physiological impact. In light of these findings and the unquestionable importance of individual differences in such research, we conducted post-hoc analyses in which participants were divided into high or low stress groups based on their scores on the stress scale (median split). However, even following this manipulation, no significant differences were evident in levels of cortisol between the non-exam and exam periods (data not shown). Notwithstanding these results and the aforementioned considerations, the data from this and other investigations (Glaser et al., 1994; Malarkey et al., 1995) suggest that increases in cortisol can not be produced reliably in the context of examination stress. As a consequence, investigators should explore the use of other naturalistic acute stressors in paradigms where alterations in levels of cortisol is a necessary outcome.

With regard to the results obtained from the cognitive tasks, it is clear that steroid hormones provide the pathway by which psychological stress may or may not affect cognitive functioning. Thus, our principal interpretation of the cognitive data in this study was guided by the levels of cortisol, and not the perceived levels of stress, exhibited by our participants. According to this approach, reduced levels of cortisol were associated with an improvement in short-term memory (when assessed by total number of words recalled), but impairments in both selective and divided attention and in the primacy effect. No effects on the task indexing auditory verbal working memory was observed. These findings may be interpreted as being consistent with the view that the effects of corticosteroids on cognition are selective (Lupien et al., 1999) in that our data demonstrated that indices of short term memory (generic and hippocampal-specific) and attention, but not auditory verbal working memory, were influenced by changes in levels of cortisol. However, the direction of the effects observed were also selective (reduced cortisol=enhanced short term memory but an impairment in attention and the hippocampal-specific index of short term memory). One explanation for this pattern of results may be proffered from an extension of Lupien and McEwen’s (1997) proposal that an inverted U-shaped relationship exists between glucocorticoids and the nature and magnitude of cognitive dysfunction. According to this hypothesis, the effect on glucocorticoids on cognition is determined by the amount of glucocorticoids, with an inverted U function determining the direction of the effect. However, our data suggest, that the direction of the effect may
also be determined by the form of cognition under investigation. Thus, it is proposed that the precise nature of the relationship between glucocorticoids and cognition, i.e., the peak of the inverted U function, is dependent on both the amount of glucocorticoid, and the form of cognition. Accordingly, our data suggest that the peak of the function may be at a lower level for generic short term memory (performance on the short term memory task was better at lower levels of cortisol) and a higher level for attentional and hippocampal-specific short term memory processes (selective and divided attention and the primacy effect were impaired at lower levels of cortisol).

There are, however, several issues worthy of further comment in our interpretation of these results. Firstly, our data have demonstrated that an increase in self-reported levels of stress and a reduction in cortisol (i.e., during the exam condition) was associated with impaired cognitive function across most of the parameters assessed in this study (apart from scores on the short-term memory task which improved and scores on the auditory verbal working memory task which did not differ significantly). Although we have argued that these results may reflect variations in the peak of the inverted U function, it is also clear that they offer some support for the hypothesised inverse relationship between stress and cognitive function, when questionnaire responses are used to determine levels of stress. Secondly, it should be noted that the apparently anomalous improvement in scores on the free recall task during the high self reported stress/low cortisol period may simply reflect the fact that the free recall task was the only one to be repeated in this investigation. Thus, despite the interval of 2–5 months between the two testing periods and the modified order of item presentation, it remains possible that the overall improvement in free recall was due to a practice effect and was not related to changes in levels of cortisol or self-reported levels of stress. Finally, the use of a naturalistic stressor as a means of manipulating levels of cortisol prevented us from examining cognitive changes in the context of clearly defined concentrations of the hormone. Indeed, it should also be noted that the cognitive assessments in this study were undertaken at random times throughout the day. Although this was intended to minimise the effects of diurnal variations in endogenous cortisol on cognitive performance, it is possible that our data were confounded by this feature of our design.

To conclude, in consort with previous research, the results from this study have demonstrated changes in cognitive performance related to significant changes in levels of salivary cortisol and self-reported levels of stress. However, our data have also shown that examination stress does not reliably produce increases in cortisol. Indeed, the increase in self-reported levels of stress during the examination period was associated with an unexpected decrease in levels of cortisol. As a consequence, the origins of the observed cognitive changes between the non-exam and exam periods remain unclear. Nevertheless, our data suggest that the effects of corticosteroids on cognitive function are indeed selective and that, if the directional differences evident in our data were not an artefact of practice effects, that the apex of the inverted U-shaped function may differ between cognitive parameters.
References


