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Associations between endogenous cortisol levels and emotional memory in young women: Influence of encoding instructions

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Abstract
The stress hormone cortisol is known to influence memory. Elevated cortisol levels as a consequence of stress or as a consequence of cortisol administration have been repeatedly shown to enhance encoding and consolidation of (emotional) memory. Whether similar associations exist between basal cortisol levels and emotional memory remains to be established. The present study therefore evaluated if resting cortisol levels are correlated with memory for emotionally arousing and neutral pictures in a sample of young healthy females ($n = 56$). A second aim of the study was to explore if the relationship between basal cortisol levels and memory might be modulated by encoding instructions (intentional vs. incidental encoding). A significant positive correlation between basal salivary cortisol levels and memory for emotionally arousing pictures in a 24 h delayed free recall test was found. Further analyses revealed that this association only occurred in the group receiving intentional encoding instructions. Results indicate that basal cortisol levels, similarly to stress induced cortisol levels, are associated with emotional memory formation. Moreover this effect seems to be modulated by encoding instructions, suggesting a role of focussed attention or arousal induced by testing in this relationship.

Keywords: *Arousal, cortisol, emotional memory, emotional enhancement effect, encoding instructions, salivary samples*

Introduction

In response to stress the hypothalamic-pituitary-adrenal axis is activated which leads to an increased secretion of cortisol (McEwen 2000; Sapolsky et al. 2000). Studies investigating the influence of elevated cortisol levels on memory have found enhancing as well as impairing effects (Wolf 2008). For example increased cortisol secretion, either in response to stress or after pharmacological cortisol administration, impairs memory retrieval (de Quervain et al. 1998; Kuhlmann and Wolf 2005; Kuhlmann et al. 2005a; Buchanan et al. 2006). In contrast (emotional) memory encoding and consolidation appears to be enhanced. Several studies have found beneficial effects of elevated cortisol levels at times of encoding or consolidation (Cahill et al. 2003; Andreano and Cahill 2006; Beckner et al. 2006; Kuhlmann and Wolf 2006b; Payne et al. 2007). This enhancing effect of cortisol on memory was often more pronounced for emotional arousing material (Buchanan and Lovallo 2001; Cahill et al. 2003; Kuhlmann and Wolf 2006b; Payne et al. 2006, 2007; Smeets et al. 2006). Cortisol thus appears to potentiate the emotional enhancement effect (LaBar and Cabeza 2006). Studies in rodents have revealed that glucocorticoids interact with arousal-induced noradrenergic activation in the amygdala, thereby strengthening memory consolidation in the adjacent hippocampus (Roozendaal et al. 2006a).

Cortisol levels not only increase in response to stress, but also show a strong circadian rhythm, characterized by a continuous decline over the course of the day (Kirschbaum and Hellhammer 1989). In addition, the interindividual variance in endogenous cortisol levels is substantial. In contrast to the experimental studies summarized above, studies that examine the relationship between basal cortisol levels and emotional memory in young healthy subjects are rare to date and have not shown consistent results (van Honk et al.

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2003; Putman et al. 2004). The question of whether cortisol and arousal interact not only in cases of stress or pharmaco-induced cortisol elevations, but also under resting conditions remains unanswered.

The current study therefore was conducted to test the associations between emotional memory and basal salivary cortisol levels. Previous research has shown enhancing effects of elevated cortisol levels on encoding and consolidation especially for emotional arousing items (Buchanan and Lovallo 2001; Cahill et al. 2003; Kuhlmann and Wolf 2006b; Payne et al. 2007). Therefore a positive correlation was expected between cortisol level and emotional memory.

Previous studies on the topic of cortisol and emotional memory have used either incidental (Buchanan and Lovallo 2001; Cahill et al. 2003; Beckner et al. 2006; Payne et al. 2007) or intentional (Kirschbaum et al. 1996; Wolf et al. 2001; Kuhlmann and Wolf 2005; Kuhlmann et al. 2005b) encoding instructions. Differences in encoding instructions might lead to differences in attention or to altered task-induced arousal as a consequence of an increased motivation to remember the items. In addition, different brain regions might be involved in incidental vs. intentional encoding (Grady et al. 1998; Bernstein et al. 2002; Stark and Okado 2003). Whether the associations between cortisol levels and memory might differ between incidental and intentional encoding instructions was a second exploratory aim of the study.

Materials and method

Sixty young female subjects aged between 19 and 35 years (23.7 ± 0.44 years; mean ± SEM) participated in this study. Four participants were excluded because of an insufficient amount of saliva for cortisol measurement. No information about the use of hormonal contraceptives or the stage of the natural menstrual cycle was collected. All participants were recruited from the university campus and written informed consent was collected from each subject. The study was approved by the national ethic committee of the German Psychological Association (Deutsche Gesellschaft für Psychologie).

Participants were tested individually on two consecutive days 24 h apart. Testing took place between 9 am and 4.30 pm Fifty five percent of the subjects were tested before 12 pm. On the first day participants filled out a mood questionnaire (for description see below). Afterwards the memory material was presented.

Participants were randomly assigned to one of the two encoding conditions. One-half of the participants were told to memorize the pictures and narratives as well as possible (intentional encoding), whereas the other half was not instructed to memorize (incidental encoding). Additionally, subjects under both conditions were informed that we were interested in their physiological reaction to the stimuli and that they therefore should empathise strongly to the individual scenes. Immediately after watching the pictures, participants filled out the mood questionnaire again. On the second day the memory tests occurred, which were unexpected for the participants in the incidental encoding condition, and were expected for the participants who received the intentional encoding instruction. After completing the memory tests on the second day, participants were asked to rate the stimuli on a 5-point Likert scale for emotional arousal. For arousal, 1 refers to the less arousing picture and 5 to the most arousing picture.

Stimuli

The stimuli and memory tests used in the present study were developed and validated in previous studies (Buchanan et al. 2001, 2003). The stimuli consisted of 5 positive (e.g. two happy girls eating ice-cream), 5 negative (e.g. a diseased child from Africa with bandages and cannulae) and 5 neutral (e.g. people leaving or entering a building) pictures, which were presented in a fixed order for 10 s each on a computer screen. Several of the pictures were chosen from the International Affective Picture System (IAPS; Lang et al. 1997) and the rest were drawn from print media sources. Each picture was accompanied by a single narrative sentence presented via ear-phones which consisted of information that was not obvious in the picture. For example, the picture with the little girls eating ice-cream was accompanied by a sentence in which the girls' names and the special kind of ice-cream they liked were mentioned.

Based on the finding that amygdala activity is linked to emotional arousal rather than valence (Kensinger 2004), and based on previous stress/cortisol studies indicating that emotional arousal rather than valence determines the strength of the cortisol effects (Buchanan and Lovallo 2001; Cahill et al. 2003; Kuhlmann and Wolf 2006b; Payne et al. 2006, 2007; Smeets et al. 2006), the two emotional valence categories (positive and negative pictures) were combined and data averaged, thereby creating a single category of emotionally arousing items.

Memory tasks

The memory tests took place 24 h after the encoding session. Firstly, the participants performed a free-recall test, for which they were told that they would have 5 min to write down everything they could remember from the pictures and narratives. In addition to the verbal instruction, participants received this instruction in written form at the top of the answer sheet. Answers were evaluated by two independent judges, who were blind to the group membership of the subjects. The agreement between the two raters was evaluated with an intra-class correlation for the total free recall

score. The intra-class correlation coefficient was high ($r_{icc} = 0.912$, $p < 0.001$) indicating good reliability. Therefore, the average score of the two raters was used. Participants scored 2 points, if the information they wrote down could be associated clearly to one of the pictures and was correct in details. One point was given for information that could be associated clearly to one of the pictures but consisted of some incorrect details. If the information was completely incorrect or could not be linked to one picture, participants got 0 points. In total the participants could score a maximum of 30 points.

The second test was a four-alternative multiple-choice test with six questions for each stimulus, which asked for information from pictures and narratives. In this task, every correct answer scored one point, so that a total of 90 points was possible. This test also allowed differentiating between memory for gist and for detail information. Gist is defined as "information which could not be changed or excluded without changing the basic story line" (Heuer and Reisberg 1990). According to Buchanan et al. (2003), 47 of the questions referred to gist information and 37 to detail information. The remaining six items could not be categorized clearly and were thus not included in the gist analysis (Buchanan et al. 2003). Here again every correct answer scored one point, so that 47 points for the gist items and 37 points for detail items were achievable. In order to allow comparisons between memory for gist and memory for detail memory performance was expressed in percentages.

Questionnaires

As an indicator of mood the "Positive and Negative Affective Scale" (PANAS, Watson et al. 1988) was used. The questionnaire consists of 20 adjectives, which are summarized into one scale for positive and one scale for negative affect. For each adjective participants had to mark on a five point Likert scale, how far the adjective described their actual state. Sums of the scale marks were made by addition of the answers to the respective items (resulting in a minimum sum of 10 per scale). Participants filled out the questionnaire twice, once before presentation of the stimuli and for the second time after the presentation.

Saliva sample

Saliva was collected using Salivette collection devices (Sarstedt, Nümbrecht, Germany). Cortisol concentrations were measured using an immunoassay (IBL, Hamburg, Germany). Inter- and intra assay variations were below 15%. Two samples were taken, one before presentation of the stimuli and the second one immediately after presentation was completed (approximately 5 min after the first saliva sample). Two samples were taken in order to obtain a more reliable and valid basal cortisol measure. Testing and thus salivary sampling was spread over the day (ranging from 9 am to 4:30 pm).

Statistical analysis

Data were analyzed with Spearman *t*-tests or ANOVAs for repeated measurements and *post hoc* adjusted paired *t*-tests. Greenhouse-Geisser corrected p values were used when indicated. Because cortisol measures did not show a normal distribution, data were log 10 transformed to approximate them to a Gaussian distribution. After transformation all data were normally distributed.

Results

Arousal ratings

The data of the arousal ratings for the pictures that were made after completion of the memory tests on the second day were analyzed using ANOVA with the within subject factor arousal (arousing vs. neutral items) and the between subject factor encoding condition (incidental vs. intentional encoding). A significant main effect of arousal was detected [$F(1,54) = 148.041$, $p < 0.001$]. No main effect for encoding condition was detected [$F(1,54) = 2.240$, $p = 0.140$]. The interaction with encoding condition did not reach significance [$F(1,54) = 0.458$, $p = 0.501$]. Participants rated the arousing items with values of 3.80 (± 0.06) and the neutral items as 2.55 (± 0.09); *post hoc t*-tests showed that this difference was significant [$t(55) = -12.211$, $p < 0.001$].

Influence of arousal and encoding condition on memory retrieval

An ANOVA with the within subject factor arousal (arousing vs. neutral items) and the between subject factor encoding condition (incidental vs. intentional encoding) was conducted for each memory test separately. There was a significant main effect of arousal for the free recall test [$F(1,54) = 71.784$, $p < 0.001$] and the multiple choice test [$F(1,54) = 16.996$, $p < 0.001$]. Analyses did not show main effects of encoding condition [free recall: $F(1,54) = 0.009$, $p = 0.925$; multiple choice: $F(1,54) = 0.617$, $p = 0.435$] or interaction effects between arousal and encoding condition [free recall: $F(1,54) = 1.616$, $p = 0.209$; multiple choice: $F(1,54) = 0.002$, $p = 0.961$]. To investigate the significant main effect of arousal further, we conducted paired *t*-tests for both memory tests. In both tests, neutral items were recalled significantly less than arousing items [free recall: $t(55) = -8.386$, $p < 0.001$; multiple choice: $t(55) = -4.165$, $p < 0.001$]. Results are displayed in Figure 1(a),(b) respectively.

Additionally an ANOVA with the within subject factors gist (gist vs. detail), arousal (arousing vs. neutral items) and the between subject factor encoding condition (incidental vs. intentional encoding) was

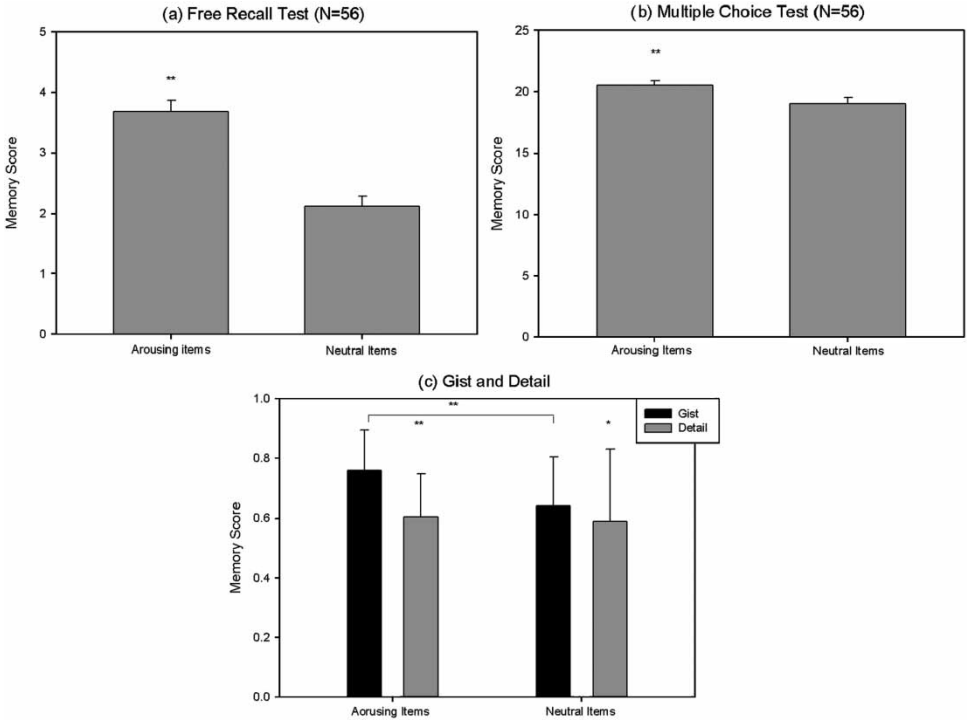

Figure 1. Mean memory scores for arousing and neutral items in the free recall test (a), the multiple choice test (b) and for gist and detail analysis of the multiple choice test (c). All comparisons are with paired *t*-tests. Participants reached a higher memory score for arousing items compared to neutral ones in the free recall test ($**p < 0.001$) and in the multiple choice test ($**p < 0.001$). Participants reached higher memory scores (expressed in percentages) for arousing ($**p < 0.001$) and neutral ($*p < 0.05$) gist information than for detail information. For the gist of the stimuli the participants remembered more emotional than neutral information ($**p < 0.001$). Values are mean ± SEM.

conducted. Results revealed a main effect for arousal [$F(1,54) = 22.044$, $p < 0.001$] and gist [$F(1,54) = 66.819$, $p < 0.001$] and a significant interaction effect between arousal and gist [$F(1,54) = 18.005, p < 0.05$]. No main effect of encoding condition [$F(1,54) = 0.770$, $p = 0.384$] was detected and none of the possible interactions with this factor were significant (all $p > 0.20$). *Post hoc t*-tests showed that participants remembered more gist than detail information for emotionally arousing [$t(55) = 11.983$, $p < 0.001$] and neutral items [$t(55) = 2.426$, $p < 0.05$]. In addition for the gist of the stimuli participants remembered more emotional than neutral information [$t(55) = -9.971$, $p < 0.001$] while no such effect was observed for details [$t(55) = -0.647$, $p = 0.521$]. Results are displayed in Figure 1(c).

Salivary cortisol

Salivary cortisol concentrations decreased slightly but significantly between the two sampling points from 7.02 (±0.54) to 5.83 (±0.44) nmol/l [$t(55) = 4.033$, $p < 0.001$]; the *t*-test was conducted with log-transformed data. In order to create a single measure indicative of the basal cortisol levels during the memory task the average of the two measures was taken. For nine participants, only one of the two saliva samples contained enough fluid for the analysis. In those cases, the available measure of the participant was used as the best estimator. Mean cortisol levels were 6.43 ± 0.47 nmol/l.

Associations between cortisol and emotional memory

Analysis for the entire sample. Bivariate Pearsons's correlations between the mean salivary cortisol concentration and the memory scores revealed a significant positive correlation between cortisol concentration and memory for arousing items in the free recall task ($r = 0.295, p < 0.05$). A smaller and non-significant correlation emerged for the neutral items ($r = 0.122$, $p = 0.372$). The scatter plots are presented in Figure 2. For the multiple choice test no significant correlation was observed (arousing items $r = -0.054$, $p = 0.693$; neutral items $r = 0.163$, $p = 0.231$).

Because of the well-known circadian rhythm of cortisol secretion (Kirschbaum and Hellhammer 1989), we additionally conducted a partial correlation analysis which controlled for time of day. This analysis ascertained that the association between salivary cortisol concentration and emotional memory was not secondary to an unspecific effect of the circadian rhythm. The correlation coefficient between salivary cortisol concentration and free recall of arousing items became only slightly smaller when time of day was partialed out ($r = 0.263$, $p = 0.052$).

Fisher's *z*-test indicated that the correlations between arousing items and cortisol concentration

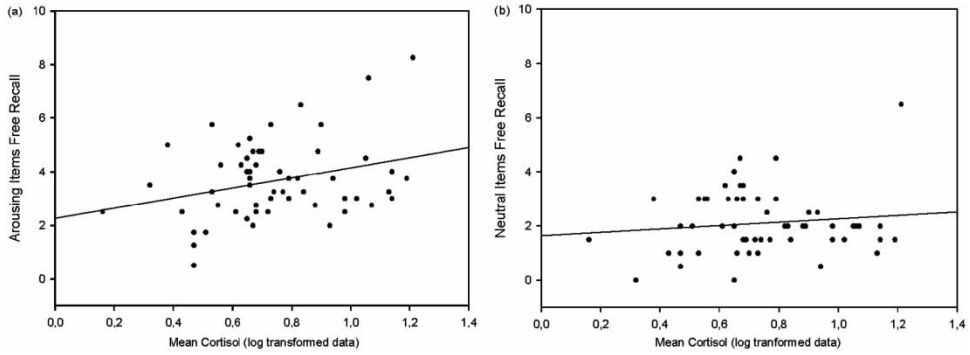

Figure 2. Scatter plots for the correlations between log transformed salivary cortisol concentration data and memory performance in the free recall test ($n = 56$) for (a) emotionally arousing items ($r = 0.295$; $p < 0.05$), (b) neutral items, not significant ($r = 0.112$, $p = 0.372$).

differed significantly from the correlation between neutral items and cortisol concentration. This was true for the correlations without ($z = 0.375$, $p < 0.05$) and with the control for time of day ($z = 0.382$, $p < 0.05$).

Influence of encoding condition

To evaluate whether intentional vs. incidental encoding influenced the observed associations between cortisol and emotional memory Pearson's correlations were conducted for the intentional and incidental group separately. Results revealed significant correlations between salivary cortisol concentration and memory for the arousing items only in the intentional encoding group (see Table I and Figure 3). A similar significant correlation was obtained when time of day was controlled for. In contrast, no association was observed between cortisol concentration and memory in the incidental encoding group (see Table I and Figure 3).

Additionally Fisher z-values were calculated to evaluate if the strength of the correlation differed between the intentional and incidental encoding group. The correlations between arousing items and cortisol concentration did significantly differ between the two groups ($r = 0.533$, $p < 0.01$). The significant difference remained when controlling for time of day ($z = 0.626$, $p < 0.01$).

Exploratory analysis

Finally, for the significant correlation between emotional memory and cortisol concentration within the intentional learning group the potential influence of two modulating factors were explored, namely time of day and gist vs. details.

Influence of time of day

Previous work has suggested that the effects of stress or cortisol treatment might differ depending on the time of day (morning vs. afternoon; Het et al. 2005; Maheu et al. 2005). So far our analysis had revealed that the associations between cortisol and emotional memory persisted, when time of day was controlled for. In order to investigate this issue further, we conducted two separate correlations for those subjects from the intentional encoding group who were tested in the morning and those subjects who were tested in the afternoon. In the morning, the correlation was $r = 0.542$, $n = 16$, $p < 0.05$. In the afternoon, the correlation was still sizable but non-significant $r = 0.385$, $n = 11$, $p = 0.242$.

Table I. Correlations between basal salivary cortisol concentrations and memory for arousing and neutral items, computed separately for the intentional and incidental encoding group.

	Cortisol	
	Without time of day as a covariate	With time of day as a covariate
Memory for arousing items		
Intentional encoding ($n = 27$)	$r = 0.482$	$r = 0.485$
	$p < 0.05$	$p < 0.05$
Incidental encoding ($n = 29$)	$r = -0.007$	$r = -0.096$
	$p = 0.969$	$p = 0.626$
Memory for neutral items		
Intentional encoding ($n = 27$)	$r = 0.339$	$r = 0.313$
	$p = 0.083$	$p = 0.120$
Incidental encoding ($n = 29$)	$r = -0.223$	$r = -0.199$
	$p = 0.245$	$p = 0.310$

Results are presented with and without time of day as a covariate.

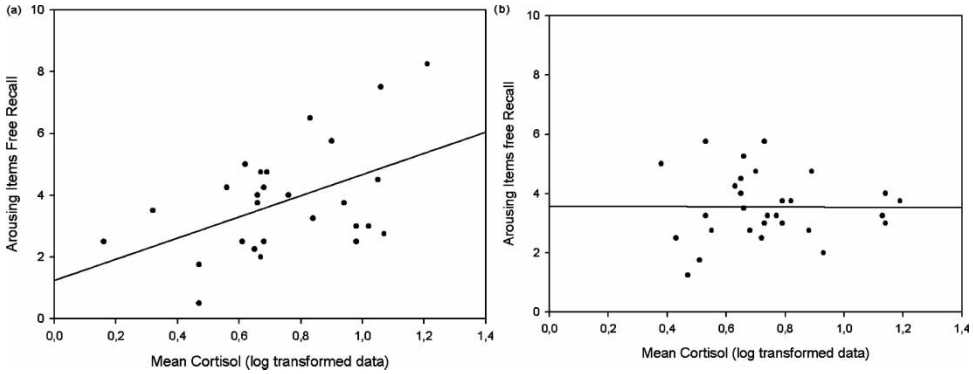

Figure 3. Scatter plots for the correlations between log transformed cortisol data and memory performance in the free recall test for emotionally arousing items in a: the intentional encoding group, significant ($r = 0.482$, $n = 27$, $p < 0.05$), b: the incidental encoding group, not significant ($r = -0.007$, $n = 29$, $p = 0.969$).

Gist vs. details

In the incidental encoding group cortisol concentration was correlated with emotional memory when tested with free recall, but not when tested with cued recall (see above). To investigate whether in the cued recall test cortisol level might be specifically related to memory for gist or details a bivariate Pearson's correlation was conducted between cortisol concentration and memory scores for arousing gist and details. However, the correlation did not reach significance for gists ($r = 0.159$, $n = 27$, $p = 0.429$) or for details ($r = 0.141$, $n = 27$, $p = 0.484$).

Associations between mood and cortisol

To assess changes in mood an ANOVA with the inner subject factors time (pre- vs. post-measurement) and the between subject factor encoding condition (incidental vs. intentional encoding) was conducted for each of the two scales separately. For positive mood there was a significant main effect of time [$F(1,54) = 96.529$, $p < 0.001$]. No main effect of encoding condition [$F(1,54) = 0.246$, $p = 0.622$] and no interaction effect between time and encoding condition [$F(1,54) = 1.215$, $p = 0.275$] was detected. For negative mood again a significant main effect of time occurred [$F(1,54) = 17.123$, $p < 0.001$]. No main effect of encoding condition [$F(1,54) = 0.937$, $p = 0.337$] and no interaction effect between time and encoding condition [$F(1,54) = 2.954$, $p = 0.091$] was detected. Post hoc t-tests revealed that participants reported an increase in negative mood [$t(55) = -4.009$, $p < 0.001$] and a decrease in positive mood [$t(55) = 9.851$, $p < 0.001$] after the slide presentation.

To investigate possible associations between emotional reactivity and basal cortisol levels bivariate Pearson's correlation were conducted. To examine the influence of changes in mood as a reaction to the stimuli, we computed a delta value for negative emotional reactivity (negative mood after presentation—negative mood before presentation of the stimuli) and positive-emotional reactivity (positive mood after presentation—positive mood before presentation of the stimuli). No significant correlations were found between subject's mood changes and average cortisol levels ($p > 0.05$).

Discussion

The present study was conducted to evaluate the relationship between basal salivary cortisol concentrations and memory for emotional arousing and neutral pictures. A second aim of the study was to evaluate possible influences of encoding strategies on this effect.

The results revealed a positive relationship between basal cortisol levels and memory for arousing items in the free recall test. Subjects with higher endogenous cortisol levels during the encoding of emotional arousing material showed superior memory for these items 24 h later. This finding fits the assumption that arousal and cortisol interact to modulate memory (Roozendaal 2002; Wolf 2008).

Our finding is in line with previous human studies which found that stress prior to encoding (Payne et al. 2007) or directly after encoding (Cahill et al. 2003; Andreano and Cahill 2006) leads to enhanced emotional memory consolidation. Similarly, pharmacological studies found enhanced emotional memory after cortisol treatment (Buchanan and Lovallo 2001; Kuhlmann and Wolf 2006b). The current results also fit well to a study by Putman et al. (2004), who observed that higher endogenous cortisol levels were associated with better memory for emotional faces tested 20 min after encoding. Our observations indicate that these facilitating effects of cortisol on encoding/consolidation can also be observed for basal cortisol levels in a 24 h recall paradigm. The present finding of a positive correlation between basal cortisol levels and memory for arousing items expands findings from stress studies to situations of endogenous

cortisol fluctuations. Studies in rodents have revealed that glucocorticoids interact with noradrenergic activation in the amygdala to enhance memory consolidation (Roozendaal et al. 2006b). In support of these findings is a recent human neuroimaging study which observed that participants with higher endogenous cortisol levels showed a stronger amygdala response to emotionally arousing slides (van Stegeren et al. 2007). A similar scenario might underlie our present results.

A second aim of the study was to evaluate if the relationships between basal salivary cortisol levels and emotional memory differ depending on the encoding strategies that were used. This analysis indicated that only participants with explicit encoding instruction (intentional encoding) showed a positive correlation between cortisol level and emotional memory. Thus the results discussed above were exclusively driven by this group. No association between cortisol and emotional memory was observed in the incidental encoding group and the correlations differed significantly between the two conditions.

Previous studies investigating the effects of stress on emotional memory encoding or consolidation have used intentional (Kirschbaum et al. 1996; Wolf et al. 2001) as well as incidental (Cahill et al. 2003; Beckner et al. 2006) encoding instructions. Similarly previous pharmacological studies used intentional (Kuhlmann and Wolf 2005; Kuhlmann et al. 2005a) as well as incidental (Buchanan and Lovallo 2001) instructions. Our study looking at basal cortisol levels suggest that cortisol influences emotional memory encoding/consolidation only in situations of intended learning and directed attention. Emotional items are known to enhance activation of the amygdala (Cahill et al. 1996; Hamann et al. 1999) and influences of cortisol rely on its interaction with noradrenergic activation in the basolateral amygdala (Cahill and McGaugh 1996; Roozendaal et al. 2006a). Recent neuroimaging evidence suggests that attention and emotional arousal sometimes interact in an additive fashion (Vuilleumier et al. 2001). Our findings might suggest that basal cortisol levels can only modulate memory when both factors (emotional arousal and attention) are present.

Another reason for the finding of an enhanced emotional memory in participants with higher basal cortisol levels and intentional encoding might be the enhanced testing induced arousal associated with the announced memory test. In a previous study, we observed that a non-arousing test situation abolished the effects of cortisol treatment on memory (Kuhlmann and Wolf 2006a). The effects on memory were only observed in test situations that induced arousal. This result was highly similar to observations made in rodents (Okuda et al. 2004). Test-induced arousal therefore seems to be a prerequisite for cortisol to influence memory, at least in pharmacological studies and possibly also in studies investigating associations between basal cortisol levels and memory. The incidental encoding group might have lacked the necessary test-induced arousal. The present results therefore suggest that heightened attention and/or test-induced arousal might strengthen the relationship between basal cortisol levels and emotional memory formation.

Cortisol is known to have a strong circadian rhythm which is characterized by a continuous decline over the course of the day in humans. It is therefore important to note that the correlation between cortisol and emotional memory persisted when time of day was controlled for. Some experimental stress studies (Maheu et al. 2005) and some pharmacological studies (Het et al. 2005) suggest that the effects of cortisol might vary depending on the time of day. Negative effects might occur in the morning, when basal cortisol levels are already relatively high. These effects might reflect an inverted U-shaped dose response curve between cortisol and memory. Indeed an inverted U-shaped relationship has been observed in some pharmacological studies (Lupien et al. 1999; Abercrombie et al. 2003; Domes et al. 2005) and a recent stress study (Andreano and Cahill 2006), but results are far from consistent. Our study suggests that at least for basal cortisol levels the relationship between cortisol and emotional memory formation appears to be linear.

In our study, we only found (within the intentional encoding group) significant associations between cortisol and free recall performance, but not between cortisol and a multiple choice cued recall task. This is in line with several previous studies (de Quervain et al. 2003; Kuhlmann et al. 2005b; Kuhlmann and Wolf 2006b).

Within the cued recall condition cortisol was neither related to emotional memory for gist nor for details. Studies in patients with amygdala lesions suggest that the amygdala is especially important for the gist memory of an emotional episode (Adolphs et al. 2005). Based on this clinical finding one could have hypothesized that cortisol is related to the gist of the emotional material. In the current study, we did not find any association between cortisol and cued recall in general, suggesting that this measure, at least in this specific task, is not sensitive to cortisol effects. Moreover cued recall memory for emotional gist was evidently good, which might have reduced the possibility to find associations with the cortisol measure.

There are several limitations of the current study which need to be considered. First of all, we cannot differentiate associations with emotional memory encoding from associations with emotional memory consolidation. The use of an immediate retrieval test similar to Kuhlmann and Wolf (2006b) would have allowed distinction of immediate from delayed effects. However, since we were interested in differentiating between intentional and incidental encoding, two separate repeated retrieval tests were not feasible.

Based on our previous findings (Kuhlmann and Wolf 2006b) and those of others (Cahill et al. 2003), we speculate that the association is driven by an effect of cortisol on emotional memory consolidation, but this remains to be firmly established.

Secondly, the present study included only a female sample. Conclusions from this study therefore cannot be extended to males. Some previous studies have reported sex differences for the relationship between cortisol and memory (Wolf et al. 2001; Cahill 2003; Andreano and Cahill 2006) and between cortisol and emotional learning (Jackson et al. 2006; Stark et al. 2006; Zorawski et al. 2006). Therefore it still has to be shown whether basal cortisol levels also relate to emotional long-term memory in males.

A third limitation of the study is the fact that we did not collect information about the menstrual cycle phase or use of oral contraceptives. There are reports suggesting that associations between cortisol and memory might only occur at a specific menstrual cycle phase (Andreano et al. 2008). Moreover, oral contraceptives appear to lead to a reduced sensitivity to cortisol, at least when it is given pharmacologically (Kuhlmann and Wolf 2005). Future studies are needed in order to explore the potential impact of sex steroids on the association between endogenous cortisol levels and emotional memory.

A fourth restriction to the present study is the fact that we did not use psychophysiological measures of arousal. It would have been important to test whether or not the intentional and incidental encoding instructions were associated with different levels of physiological arousal.

In sum we report a positive correlation between basal cortisol levels and memory for arousing items in a sample of healthy women. Interestingly this association was only apparent in those subjects who had received explicit encoding instructions. Thus, focused attention or a stronger test-induced arousal might be a prerequisite for the occurrence of beneficial cortisol effects on emotional memory, at least when tested under resting (non-stress) conditions. Our findings illustrate that cortisol is related to emotional memory not only under circumstances of stress or pharmacological glucocorticoid treatment, but also in situations when cortisol levels vary within the basal range.

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