**SUPPLEMENTAL MATERIAL**

**Stress alters the neural context for building new memories**

**Jacqueline Katharina Meier1,** **Mathias Weymar2, and Lars Schwabe1**

1 Department of Cognitive Psychology, University of Hamburg, 20146 Hamburg, Germany;

2 Department of Biological Psychology and Affective Science, University of Potsdam, 14476 Potsdam, Germany

Corresponding author: Prof. Dr. Lars Schwabe

University of Hamburg

Department of Cognitive Psychology

20146 Hamburg, Germany

e-mail: Lars.Schwabe@uni-hamburg.de

phone: +49-40-42838-5950

fax: +49-40-42838-4729

**Running title: Neural context for memory formation under stress**

**Supplemental results**

**Stress-induced changes in neural activity after stimulus onset**

Statistical analyses based on spectral power after stimulus onset showed that there were neither stress-induced modulations of spectral power within the crucial frequencies (i.e. theta and high gamma) nor within alpha and low gamma power. Nevertheless, there were stress effects on the subsequent memory effect (SME) within high and low beta band during a time window between 1500 to 2000 ms relative to stimulus onset (Figure S1A-F): Post-stimulus high beta activity was significantly lower for subsequently remembered (vs. forgotten) neutral pictures (*t*(27) = 2.1; *p* < .045; Cohen‘s *d* = .398, but not negative pictures (*t*(27) = 0.44; *p* = .663; Cohen‘s *d* = .083), in non-stressed controls. In the stress group high beta activity was significantly lower for subsequently remembered (vs. forgotten) negative pictures (t(23) = 4.04; p < .001; Cohen‘s d = .825), but not for neutral pictures (t(23) = 0.69; p = .493; Cohen‘s d = .142). Additionally, low beta during 1500 to 2000 ms after stimulus onset was also significantly lower for subsequently remembered (vs. forgotten) negative pictures but not for neutral pictures in the stress group (negative pictures: t(23) = 3.74; p < .001; Cohen‘s d = .763; neutral pictures: t(23) = 0.06; p = .949; Cohen‘s d = .013). In the control group, however, low beta band was significantly lower exclusively for neutral pictures in control participants (neutral pictures: t(27) = 2.76; p < .01; Cohen‘s d = .552; negative pictures: t(27) = 0.22; p = .83; Cohen‘s d = .041). The topographical distribution of both effects covered right temporal regions. Thus, stress effects on spectral power during pre- and post-stimulus time windows differed in (i) the crucial frequency (theta and high gamma within pre-stimulus time window vs. low and high beta within post-stimulus time window) and (i) topography (central parietal and left temporal for pre-stimulus time window vs. right temporal clusters for post-stimulus time window). Post-hoc analysis of phase-amplitude coupling during the post-stimulus interval revealed that there were no effects of stress on subsequent memory (valence x memory × group interaction, all *F*(1, 50) < 4.97; all *p* > .052; all *ω*2 < .028).

**Stress response, memory performance and demographics for the 52 participants included in the EEG analysis**

The stress response, memory performance and demographics of the 52 participants included in the EEG analysis were comparable to those of the entire sample (N = 69).

**Successful stress manipulation**

Significant subjective and physiological changes in response to the SECPT confirmed the successful stress induction. Compared to participants in the control group, participants exposed to the SECPT experienced the treatment as significantly more stressful, painful, difficult and/or unpleasant than those in the control condition (all *t*(50) < 6.2; all *p* < .001; all Cohen‘s *d* < 2.079; Table S1). At the physiological level, the exposure to the SECPT elicited significant increases in both diastolic and systolic blood pressure (group × time point of measurement interaction, both *F*(5, 245) > 8.2; both *p* < .001; both *ω*2> .096). As shown in Table S1, groups had comparable blood pressure before and after the SECPT and control manipulation, respectively (all *t*(50) < 0.35; all *p* > .145; all Cohen‘s *d* < .097), while participants in the stress condition had significantly higher blood pressure than those in the control condition during the hand immersion (both *t*(50) > 6.34; both *p* < .001; both Cohen‘s *d* > 1.545). Finally, salivary cortisol concentrations increased in response to the SECPT but not after the control manipulation (group × time point of measurement interaction, *F*(4, 188) = 8.1; *p* < .001; *ω*2= .061). Participants of the stress and control groups had comparable cortisol concentrations at baseline and immediately after the SECPT (all *t*(47) < 0.34; all *p* > .413; all Cohen‘s *d* < .097), whereas cortisol levels were significantly higher in the stress group than in the control group 20 and 40 minutes after the SECPT (both *t*(47) < 3.7; both *p* < .001; both Cohen‘s *d* < 1.057). At 60 minutes after the treatment, stress-induced cortisol concentrations returned to the level of the control group (*t*(47) = 1.81; *p* = .077; Cohen‘s *d* = .516).

**Emotional memory enhancement**

At recognition testing 24 hours after encoding, groups did not differ in MDBF scores (all *F*(1, 50) < 0.96; all *p* > .331; all < .000), blood pressure (both *t*(46) < 0.62; both *p* > .54; both Cohen‘s *d* < .181), or salivary cortisol (*t*(48) = 1.31; *p* = .195; Cohen‘s *d* = .371).

As expected, recognition performance was overall significantly better for negative than for neutral pictures as reflected in a higher d’ (*F*(1, 50) = 20.61; *p* < .001; = .082; Table S2). The stress and control groups, however, did not differ in their overall memory performance (*F*(1, 50) = 0.23; *p* = .634; = .000) or the emotional memory enhancement (valence × group interaction, *F*(1, 50) = 0.57; *p* = .454; = .000). Confidence ratings were higher for remembered ratings than for forgotten pictures (*F*(1, 50) = 151; *p* < .001; = .543). Confidence ratings did not differ between stimuli valence (valence × memory interaction, *F*(1, 50) = 1.37; *p* = .248; = .001) or groups (*F*(1, 50) = 0.00; *p* = .986; = .000; memory × group interaction, *F*(1, 50) = 0.21; *p* = .648; = .000; valence × group interaction, *F*(1, 50) = 0.06; *p* = .811; = .000; valence × memory × group interaction, *F*(1, 50) = 0.2; *p* = .654; = .000).

**Control variables**

As shown in Table S3, groups did not differ in subjectively reported chronic stress levels, depressive mood, state or trait anxiety (all *t* (46) < 0.19, all *p* > .361; all Cohen‘s *d* < .05).

**Pre-stimulus effects in a sample with a minimum miss-rate of 10 percent**

In our initial analyses, we did not apply any criteria for a minimal number of misses (average number of misses: M = 24.33, SEM = 2.03). However, we computed all analyses again considering only the participants who had at least 10 percent misses (N = 27). This re-analysis, however, led largely to comparable results as our analysis for the full sample (see Table S4).

**Supplementary tables**

**Table S1: Subjective stress ratings and blood pressure before, during, and after the SECPT or control manipulation (N = 52).**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  |  | **Control** | | **Stress** | |
| Subjective assessments | Difficulty | 6.43 | (3.7) | 69.2\* | (5.6) |
| Stressfulness | 9.3 | (4.0) | 62.1\* | (4.9) |
| Painfulness | 5.7 | (3.6) | 73.8\* | (5.4) |
|  | Unpleasantness | 12.9 | (5) | 70\* | (5.9) |
| Systolic blood pressure (mmHg) | Before hand immersion | 102.7 | (4.0) | 104.9 | (5.2) |
| During hand immersion | 108.1 | (1.7) | 129.9\* | (3.2) |
| 5 minutes after hand immersion | 104.1 | (2.1) | 112.5 | (2.6) |
|  | 20 minutes after hand immersion | 105.9 | (1.6) | 107.3 | (2.4) |
|  | 40 minutes after hand immersion | 107.0 | (1.8) | 108.7 | (2.3) |
|  | 60 minutes after hand immersion | 107.0 | (1.8) | 109.5 | (2.7) |
|  | 24 after hand immersion | 109.8 | (1.8) | 111.6 | (2.4) |
| Diastolic blood pressure (mmHg) | Before hand immersion | 72.8 | (2.2) | 77.5 | (2.3) |
|  | During hand immersion | 74.8 | (2.0) | 95.2\* | (3.3) |
|  | 5 minutes after hand immersion | 73.7 | (1.9) | 79.6 | (2.6) |
|  | 20 minutes after hand immersion | 75.0 | (1.8) | 78.1 | (2.3) |
|  | 40 minutes after hand immersion | 75.2 | (1.8) | 77.5 | (2.1) |
|  | 60 minutes after hand immersion | 75.5 | (1.8) | 79.9 | (2.1) |
|  | 24 after hand immersion | 69.4 | (1.9) | 70.9 | (1.3) |

Data represent means; SEMs are given in parentheses.\* *p* < .01 (stress vs. control).

**Table S2: Recognition performance (N = 52).**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Control** | | | | **Stress** | | | |
|  | neutral | | negative | | neutral | | negative | |
| d’ | 2.13 | (0.14) | 2.6 | (0.1) | 2.12 | (0.15) | 2.46 | (0.12) |
| Hit rate (%) | 0.86 | (0.04) | 0.91 | (0.01) | 0.89 | (0.04) | 0.89 | (0.01) |
| False alarm rate (%) | 0.14 | (0.02) | 0.14 | (0.02) | 0.18 | (0.03) | 0.16 | (0.02) |

Data represent means; SEMs are given in parentheses.

**Table S3: Control variables (N = 52).**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  |  | **Control** | | **Stress** | |
| BDI |  | 5.76 | (1.15) | 6.22 | (0.82) |
| STAI scales | State Anxiety | 36.41 | (1.91) | 36.88 | (1.62) |
| Trait Anxiety | 35.04 | (1.75) | 37.6 | (2.12) |
| TICS scales | Work overload | 10.88 | (1.31) | 12.19 | (1.44) |
|  | Social overload | 6.04 | (0.95) | 7.39 | (0.94) |
|  | Performance pressure | 12.26 | (1.47) | 13.77 | (1.12) |
|  | Work discontent | 10.00 | (1.13) | 10.42 | (1.19) |
|  | Excessive workload | 4.41 | (0.60) | 5.96 | (0.96) |
|  | Lack of social recognition | 3.56 | (0.67) | 3.77 | (0.61) |
|  | Social tension | 4.29 | (0.76) | 4.92 | (0.75) |
|  | Social isolation | 7.04 | (1.06) | 6.36 | (0.76) |
|  | Chronic worrying | 3.88 | (0.63) | 5.96 | (0.69) |
|  | TICS screening scale | 10.73 | (1.37) | 15.00 | (1.90) |

Data represent means; SEMs are given in parentheses. BDI, Beck Depression Inventory; STAI, State-Trait Anxiety Inventory; TICS, Trier Inventory of Chronic Stress.

|  |
| --- |
| **Table S4: Pre-stimulus effects for N = 52 and N = 27.** |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Pre-stimulus SME | **N = 52** | | | **N = 27** | | |
| *F*-value | *p*-value | Effect size (*ω*2*)* | *F*-value | *p*-value | Effect size *(ω*2*)* |
| Theta power | | | | | | |
| *Memory* | 12.32 | .001 | .106 | 2.59 | .120 | .032 |
| *Group × memory* | 4.05 | .050 | .031 | 6.04 | .021 | .096 |
| High gamma power | | | | | | |
| *Valence × memory × group* | 5.86 | .002 | .042 | 1.39 | .250 | .006 |
| Theta-low beta PAC | | | | | | |
| *Valence × memory × group* | 7.28 | .010 | .043 | 4.32 | .048 | .032 |
| Theta-high gamma PAC | | | | | | |
| *Valence × memory × group* | 4.43 | .040 | .028 | 5.41 | .028 | .074 |
| Theta-high beta PAC | | | | | | |
| *Valence × memory × group* | 4.72 | .035 | .038 | 5.01 | .034 | .081 |



**Figure S1:** **Subsequent memory effect of post-stimulus power for each group.** (A) Topographic distribution of low beta power based on searchlight clustering. (B) Mean low beta power based on searchlight clustering (averaged across electrodes with accuracy > 0.6) within an interval between 1.5 to 2 s relative to stimulus onset as a function of recognition (HIT vs. MISS) and experimental group (stress vs. control) for neutral pictures. (C) Mean low beta power based on searchlight clustering (averaged across electrodes with accuracy > 0.6) within an interval between 1.5 to 2 s relative to stimulus onset as a function of recognition (HIT vs. MISS) and experimental group (stress vs. control) for negative pictures. (D) Topographic distribution of high beta power based on searchlight clustering. (E) Mean high beta power based on searchlight clustering (averaged across electrodes with accuracy > 0.6) within an interval between 1.5 to 2 s relative to stimulus onset as a function of recognition (HIT vs. MISS) and experimental group (stress vs. control) for neutral pictures. (F) Mean high beta power based on searchlight clustering (averaged across electrodes with accuracy > 0.6) within an interval between 1.5 to 2 s relative to stimulus onset as a function of recognition (HIT vs. MISS) and experimental group (stress vs. control) for negative pictures. Data represent means ± SEM. \* *p* < .05 and \*\* *p* < .001.