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Reappraisal inventiveness: impact of appropriate brain activation during efforts to generate alternative appraisals on the perception of chronic stress in women*

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ABSTRACT

Background and objectives: Previous research indicated that more left-lateralized prefrontal activation during cognitive reappraisal efforts was linked to a greater capacity for generating reappraisals, which is a prerequisite for the effective implementation of cognitive reappraisal in everyday life. The present study examined whether the supposedly appropriate brain activation is relevant in terms of more distal outcomes, i.e., chronic stress perception.

Design and methods: Prefrontal EEG alpha asymmetry was recorded while female participants were generating reappraisals for stressful events and was correlated with their self-reported chronic stress levels in everyday life ($n = 80$).

Results: Women showing less left-lateralized brain activity in the ventrolateral prefrontal cortex during cognitive reappraisal efforts reported experiencing more stress in their daily lives. This effect was independent of self-efficacy beliefs in managing negative emotions.

Conclusion: These findings underline the practical relevance of individual differences in appropriate brain activation during emotion regulation efforts and the assumedly related basic capacity for the generation of cognitive reappraisals to the feeling of being stressed. Implications include the selection of interventions for the improvement of coping with stress in women in whom the capability for appropriate brain activation during reappraisal efforts may be impaired, e.g., due to depression or old age.

Introduction

Stress is an inevitable part of daily life, yet if chronically enhanced, it can promote the development of affective disorders (Hammen, 2005; Hankin et al., 2015; McKlveen et al., 2016). Importantly, it is the appraisal of a stressful event rather than the event itself that figures prominently in the emotional stress response (Ellsworth & Scherer, 2003; Lazarus, 1993). As such, it is learning how to successfully reappraise adverse life events that may serve as a protective factor for severe chronic stress (Woud, Postma, Holmes, & Mackintosh, 2013). Involved in emotion regulation as well as stress coping, cognitive reappraisal refers to the process of re-interpreting the subjective meaning of an emotionally evocative event and thereby changing its emotional impact (Gross & John, 2003; Lazarus & Alfert,

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1964; Lazarus & Folkman, 1984). Cognitive reappraisal is considered particularly powerful in successfully coping with stressful circumstances (Augustine & Hemenover, 2009; Webb, Miles, & Sheeran, 2012).

Adding to the valuable research on the habitual or typical use of cognitive reappraisal (see, e.g., Cutuli, 2014 for review), recent research focused on reappraisal ability in the psychometric sense, that is, to what degree people are theoretically capable of implementing cognitive reappraisal (psychometric concept of maximum performance; Cronbach, 1970). This more fundamental capacity for cognitive reappraisal was investigated in terms of an individual's inventiveness in generating alternative appraisals of stressful situations, which can be regarded as a prerequisite for the effective implementation of cognitive reappraisal in everyday life (Weber, Assunção, Martin, Westmeyer, & Geisler, 2014). Continuing this strand of research, the present study was intended to fill a certain gap in the literature: Several studies supported a link between habitual tendencies to use cognitive reappraisal more often and better stress coping (e.g., Moore, Zoellner, & Mollenholt, 2008; Myers et al., 2012; Troy, Wilhelm, Shallcross, & Mauss, 2010). Many studies examined which brain structures are activated during reappraisal of negative stimuli (e.g., Buhle et al., 2014; Hallam et al., 2015). But there has been a relative lack of research addressing the neural equipment that allows individuals to use cognitive reappraisal effectively, with respective repercussions for how they feel in their daily lives. This research question is relevant, because this basic equipment of an individual will determine whether promoting attempts to use cognitive reappraisal more often, e.g., in cognitive behavioral therapy, will be effective at all. In individuals in whom it is impaired on account of declines in relevant brain functions, for instance, depressed (Dillon & Pizzagalli, 2013; Johnstone, van Reekum, Urry, Kalin, & Davidson, 2007; Townsend et al., 2013) older people (Opitz, Rauch, Terry, & Urry, 2012), or individuals who are neurologically impaired for other reasons, training of other strategies such as distraction could then be more effective (Scult, Knodt, Swartz, Brigidi, & Hariri, 2017; Smoski, LaBar, & Steffens, 2014).

Recent experimental findings identified neural correlates of the inventiveness in generating alternative appraisals of stressful situations: More left-lateralized activation in the lateral prefrontal cortex during reappraisal efforts (assessed by EEG alpha asymmetry), specifically in the ventral region, was linked to a greater number and diversity of generated reappraisals (Papousek et al., 2017). The location was in line with several brain imaging studies which had indicated the involvement of lateral prefrontal cortex, particularly in the left hemisphere, in the generation of reappraisals (Dillon & Pizzagalli, 2013; Dörfel et al., 2014; Kalisch, 2009; Ochsner, Silvers, & Buhle, 2012; Phan et al., 2005; Price, Paul, Schneider, & Siegle, 2013; for meta-analysis, see Buhle et al., 2014). These findings, by implication, suggested that the proneness or capability to recruit the supposedly appropriate brain circuits when faced with the demand of reappraising a stressful event (mirrored in left-lateralized prefrontal activation) is also beneficial in terms of more distal outcomes such as individuals' chronic stress experience (Papousek et al., 2017). However, this has not yet been empirically demonstrated. Accordingly, the purpose of this study was to examine if the pattern of activation that was shown to be related to greater reappraisal inventiveness in previous research (Papousek et al., 2017) is relevant in terms of chronic stress perception.

We studied this issue in the context of laterality research, which focuses on relative differences of activation in the left and right cortical hemispheres and has proved to be relevant in this particular context. According to the capability model of frontal EEG alpha asymmetry (Coan, Allen, & McKnight, 2006), the individual's capability or typical mode to adapt to the specific demands of a certain situation is reflected in the individual's recruitment of appropriate brain circuits in that situation, which produces characteristic asymmetry changes in the brain. These asymmetry changes, recorded in a respective context, index the individual's capability to effectively process the specific demands and, consequently, may be indicative of traits related to psychological health and well-being (see also Allen & Reznik, 2015; Beeney, Levy, Gatzke-Kopp, & Hallquist, 2014; Cole, Zapp, Nelson, & Perez-Edgar, 2012; Goodman, Rietschel, Lo, Costanzo, & Hatfield, 2013; Liu, Sarapas, & Shankman, 2016; Papousek, Reiser, et al., 2013, 2014; Pérez-Edgar, Kujawa, Nelson, Cole, & Zapp, 2013; Stewart, Coan, Towers, & Allen, 2014). More generally, several studies indicated functional deficits

when brain circuits that are associated with these functions were inadequately activated, and that lateralized activation of specific relevant brain regions was linked to better performance on associated tasks (Davidson, Chapman, Chapman, & Henriques, 1990; Gur et al., 1994, 2000; Gur & Reivich, 1980; Papousek, Murhammer, & Schulter, 2011; Papousek & Schulter, 2004; Wendt & Risberg, 1994). The capability model represents one of several important advancements of prefrontal brain asymmetry research that in part may be hampered by too simplistic approaches such as the reliance on resting data (see Miller, Crocker, Spielberg, Infantolino, & Heller, 2013 for a critical review).

While not specifically concerned with the recruitment of relevant brain regions during efforts to cognitively reappraise stressful events, the findings of several studies in the tradition of EEG alpha asymmetry research suggested importance of relative left-sided prefrontal activation for coping with stressful events (Blackhart & Kline, 2005; Goodman et al., 2013; Jackson et al., 2003; Lopez-Duran, Nusslock, George, & Kovacs, 2012; Papousek et al., 2014). The hypothesized link is additionally suggested by an fMRI study showing cognitive reappraisal efforts to elicit left-lateralized ventrolateral prefrontal activation in healthy individuals, whereas depressed patients displayed bilateral prefrontal activation (Johnstone et al., 2007). The authors interpreted the absence of clear left-lateralized activation as inefficient or inappropriate engagement of prefrontal regulatory circuitry, which may relate to the difficulties of depressed patients to adequately cope with adverse events (e.g., Beauregard, Paquette, & Levesque, 2006). Likewise, a lack of left-frontal activation during reappraisal efforts was found in elderly people, which concomitantly diminished their reappraisal success in terms of decreasing negative affect (Opitz et al., 2012). In accordance with the capability model of frontal EEG asymmetry, in the present study EEG alpha asymmetry was recorded while participants were generating cognitive reappraisals in the Reappraisal Inventiveness Test (RIT; Weber et al., 2014). While typical cognitive reappraisal tasks make it difficult to ascertain that participants are actually compliant when asked to use this specific strategy (mostly while watching negative affective material), and a large proportion of participants seem to actually not adhere to specific emotion regulation instructions (Demaree, Robinson, Pu, & Allen, 2006), using the RIT allowed to objectively monitor participants' compliance with reappraisal instructions. In particular, the RIT involves the active generation of many different reappraisals of anger-eliciting scenarios, depicting a conflictual relationship with another person who wilfully or carelessly induces harm. Anger regulation constitutes a relevant context, because higher levels of anger experience are related to perceptions of higher stress levels (e.g., Diong et al., 2005; Johnson, Galambos, & Krahn, 2014).

In order to exclude that potential correlations between individual differences in brain activation during efforts to generate reappraisals and perceptions of chronic stress are due to efficacy beliefs as the decisive factor, we also assessed the participants' self-efficacy beliefs in managing negative emotions. Self-efficacy beliefs in managing emotional experiences refer to a personality trait that may affect the individual's appraisal of his or her circumstances and responses to stressful events and, hence, may strongly influence self-reported chronic stress levels (Petrides, 2011; Petrides, Pita, & Kokkinaki, 2007). Reciprocal influences between cognitive-emotional abilities such as reappraisal inventiveness and perceived efficacy in managing emotions seem likely. Self-efficacy beliefs are supposed to affect to what degree individuals make efforts to actively cope with stressful events (i.e., make use of their abilities), and better abilities should at least to some extent predict more perceived efficacy in managing one's emotions (Bandura, 2001; Gohm, Corser, & Dalsky, 2005). There is evidence for substantial correlations between perceived efficacy in managing emotions and several indexes of well-being (Caprara & Steca, 2005; Freudenthaler, Neubauer, Gabler, Scherl, & Rindermann, 2008; Lightsey et al., 2012; Milioni et al., 2015; Palesh et al., 2006).

We hypothesized that individuals showing brain activation patterns during efforts to generate cognitive reappraisals that were suggested to be more appropriate (efficient) by previous research (i.e., more relative left-lateralized ventrolateral prefrontal activation; Papousek et al., 2017) will report less chronic stress experience in everyday life. In line with the EEG asymmetry research tradition, we infer increased cortical activation from relative decreases of alpha power (see Allen, Coan, & Nazarian, 2004 for a review of evidence and Harmon-Jones, 2006; Michels et al., 2010;

Scheeringa et al., 2011 for recent experimental research supporting the assumption that EEG alpha band activity obtained in time frames of several seconds or minutes is inversely related to cortical activity). Furthermore, we expected at least some of the shared variance between brain activation during reappraisal efforts and chronic stress experience to be independent of perceived efficacy in managing emotions, thereby corroborating the importance of the brain's basic capability to generate reappraisals for perceptions of chronic stress. Finally, it was tested whether chronic stress perception may also be correlated with overt performance differences on the used experimental cognitive reappraisal task, taking different types of cognitive reappraisal into account.

Methods

Participants

Eighty participants aged between 18 and 35 years ($M = 22.7$, SD = 3.5) completed the experiment with all required data. All participants were university students enrolled in various fields and female. A student sample was chosen, because the contents of the used material (RIT; Weber et al., 2014) had been tailored for a student population. A female-only sample was tested in order to avoid any confounding effects produced by potential gender differences in emotion-related abilities and habits (e.g., Domes et al., 2010; Freudenthaler & Papousek, 2013). Accordingly, women may be more motivated to downregulate anger for social reasons (Evers, Fischer, Rodriguez Mosquera, & Manstead, 2005) and reported using both adaptive and maladaptive emotion regulation strategies more frequently than men (Nolen-Hoeksema & Aldao, 2011). The sample size was based on a priori power analysis considering effect sizes observed in previous relevant research, common retest-correlations among repeated measures of EEG variables, and commonly recommended type 1 error probability ($α = .05$) and power ($1 − β = 0.80$; Bühner & Ziegler, 2009). Women who reported having a neuropsychiatric disease or using psychoactive medication were not included in the study. Seven out of the 80 participants were smokers. Right-handedness was confirmed using a standardized hand skill test (Papousek & Schulter, 1999; Steingrüber & Lienert, 1971). Participants were requested to refrain from alcohol for 12 hours and from coffee and other stimulating beverages for two hours prior to their lab appointment, and to come to the session well rested. The study was performed in accordance with the American Psychological Association's Ethics Code and the Declaration of Helsinki and was approved by the local ethics committee. Participants gave their written consent to participate in the study.

Reappraisal task

The four items of the RIT (Weber et al., 2014) were used to establish situations in which the participants were required to generate alternative appraisals of stressful events. Four additional items were added that matched the main characteristics of the original ones (Papousek et al., 2017). The items consist of anger-eliciting vignettes that are supplemented by a matching photograph to make the situation more vivid. Each vignette was presented on a computer screen for 20 s. Participants were instructed to imagine the situation happening to them and to generate as many different ways as possible to think about or appraise the situation in a way that diminishes anger. They were instructed to press a button whenever a new appraisal came to mind and to vocalize the idea concisely in one or two short sentences immediately after pressing the button. Then they were asked to press the button again, and the task was resumed until the allotted time of 3 min had elapsed. In doing so, EEG segments related to the production of reappraisals could be separated from segments contaminated with the production of speech. This protocol has proved to be eminently suitable in previous relevant research (Fink, Benedek, Grabner, Staudt, & Neubauer, 2007; Papousek et al., 2017). Participants' vocal responses were audiotaped for later analysis, and adherence to the protocol was carefully monitored.

EEG recording and quantification

EEG was recorded from 19 channels according to the international 10–20 system, using a Brainvision BrainAmp Research Amplifier (Brain Products) and a stretchable electrode cap, referenced to the nose and re-referenced offline to a mathematically averaged ears reference (Hagemann, 2004). Impedance was kept below 5 kΩ for all electrodes. EOG measures were obtained for identification of ocular artifacts. All data were inspected visually, in order to eliminate intervals in which ocular or muscle artifacts occurred. For the assessment of EEG asymmetry during the reappraisal task, only the time frames in which participants were mentally generating alternative appraisals were used, that is, reading and speaking intervals were excluded. To preclude potential influences of finger movements on frontal EEG asymmetry (e.g., Harmon-Jones, 2006; Peterson, Shackman, & Harmon-Jones, 2008), time frames were cut with a distance of 450 ms to each button press (cf. Shibasaki & Hallett, 2006). Power spectra (epoch length 1 s, overlapping 50%, Hanning window) were averaged across all artifact-free intervals for an individual. Following the common approach in the field, power within the alpha frequency band (8–12 Hz) was used for the analyses. Laterality coefficients (LC) were computed for each electrode pair as $LC = ((R - L)/(R + L)) \times 100$, where R denotes the electrode over the right hemisphere and L denotes the homologous electrode over the left hemisphere. This asymmetry ratio is equivalent to another common metric ($\ln R - \ln L$), with which it is virtually perfectly correlated (Davidson, 1988; Papousek & Schulter, 2002). However, LC allows easier comparison of data from different studies, different frequency bands, and locations (Pivik et al., 1993), and has been used in numerous EEG studies in relevant research contexts (e.g., Papousek et al., 2011, 2014; Papousek, Reiser, et al., 2013; Papousek, Reiser, Weber, Freudenthaler, & Schulter, 2012; Papousek & Schulter, 2004; Papousek, Schulter, et al., 2013). Positive values of LC indicate relatively greater left than right hemisphere cortical activity (inverse of alpha).

Reappraisal inventiveness

Participants' responses to the RIT items were used for the assessment of behavioral measures of their reappraisal inventiveness. Following the scoring procedure of the RIT (Weber et al., 2014), RIT-fluency was calculated as the total number of generated non-identical reappraisals (Cronbach's $α = .93$). Reappraisals were categorized according to the category scheme of the RIT (Weber et al., 2014): generating positive aspects (positive re-interpretation); problem-oriented (casting the situation in terms of how the induced harm could be reduced); de-emphasizing the negative impact of the harm induced and/or the instigator's wrong-doing; revenge (casting the situation in terms of getting even). Responses were independently rated by two experimenters. Inter-rater reliabilities with two-way random, single measure ICC (95% confidence intervals, consistency) were = .93 for RIT-fluency, and ICC = .87, ICC = .92, ICC = .95, and ICC = .93 for the total number of responses categorized as positive re-interpretation, problem-oriented, de-emphasizing, and revenge, respectively.

Self-report measures

Chronic stress experience. The short form (screening scale) of the Trier Inventory for Chronic Stress (TICS; Schulz, Schlotz, & Becker, 2004) was used for the assessment of participants' perceptions of chronic stress during the last three months (12 items rated on 5-point Likert scales ranging from 0 (never) to 4 (very often), $α = .89$). Scores ranged from 0 to 36 ($M = 16.9$, $SD = 8.7$).

Depression. The Center for Epidemiologic Studies depression scale (CES-D, German version, Hautzinger & Bailer, 1993) is composed of 20 items, rated from 0 (rarely or none of the time – less than 1 day) to 4 (most or all of the time – 5 to 7 days; $α = .82$). It refers to mood and attributions over the past week and is designed for measuring sub-clinical depressive experiences in the general population (Wood, Taylor, & Joseph, 2010). Scores ranged from 1 to 31 ($M = 11.7$, $SD = 6.6$).

Perceived efficacy in managing negative emotions. The emotion regulation subscale of the Self-report Emotional Ability Scale (SEAS; Freudenthaler & Neubauer, 2005) was used, which assesses how able individuals feel to regulate negative affect in their everyday life. It includes six items (rated on 6-point Likert scales; $a = .75$).

Procedure

Participants completed the handedness test and were seated in an acoustically and electrically shielded examination room. After electrodes were attached, participants were instructed to relax and sat quietly with closed eyes for two minutes to adapt. Subsequently, the EEG was recorded during an initial two minutes resting condition (open eyes, participants were instructed to rest their eyes on a filled green circle on the screen). Then, the participants were instructed for the task and were given a practice item. After completing the task (while the EEG was again recorded) electrodes were detached, and the participants were given the opportunity to wash and dry their hair. Finally, they completed the questionnaires.

Statistical analysis

Three linear regressions were calculated using resting EEG alpha asymmetry at an F7/F8, Fp1/Fp2, or F3/F4 to predict asymmetry during the generation of reappraisals at the respective electrode site. The residualized scores of prefrontal alpha asymmetry during the generation of reappraisals were used in the main analysis. This was done to ensure that the analyzed variability was due to the activation during the generation of reappraisals, and not to individual differences in baseline levels at that electrode site (i.e., to general inter-individual differences irrespective of the demands at hand; cf. Papousek et al., 2014). The main research question was examined with one standard multiple regression analysis using prefrontal alpha asymmetry during the generation of reappraisals at the three prefrontal electrode sites (F7/F8, Fp1/Fp2, and F3/F4) and perceived efficacy in managing negative emotions (SEAS) as predictors, and chronic stress (TICS) as the dependent variable. An analogous analysis was done with depression (CES-D) as the dependent variable. These results can be found in the supplemental material.

In order to test for the possibility that perceived efficacy in managing negative emotions mediates the relationship between prefrontal asymmetry and chronic stress, an additional mediation analysis was performed using PROCESS (Hayes, 2013). PROCESS is based on the regression-based path-analytic framework and estimates the indirect effect and bias-corrected confidence intervals. An indirect effect is considered significant when the confidence intervals do not include zero. The level of this significance was assessed using Sobel tests. All analyses were based on 5000 bootstrapping samples (Hayes, 2013).

Additionally, a multiple regression analysis was run to test whether more appropriate (i.e., more left-lateralized) prefrontal activity during efforts to generate reappraisals predicts higher performance on the task (cf. Papousek et al., 2017). Finally, it was also tested in analogous multiple regression analyses, whether perceptions of stress may be predicted by the behavioral indexes of reappraisal inventiveness.

Results

Brain activation during the generation of alternative appraisals

EEG alpha asymmetry during efforts to generate cognitive reappraisals at the ventral electrodes (F7/F8) predicted participants' perceptions of chronic stress in daily life ($sr = -.24$, $p = .006$; $F(4,75) = 16.2$, $p < .001$). Women showing less left-lateralized activity at that site while generating reappraisals reported greater levels of chronically experienced stress. This relationship was independent of the

participants' efficacy beliefs in managing negative emotions, which were correlated with perceptions of chronic stress on their part ($r = -.63$, $p < .001$). No relationship was observed between chronic stress and EEG alpha asymmetry during reappraisal generation at the most rostral (Fp1/Fp2; $sr = -.04$, $p = .660$) and the dorsal electrode positions (F3/F4; $sr = -.15$, $p = .073$). See Table 1 for a summary of the results of the main analysis. When perceived efficacy in managing negative emotions is omitted from the regression, the relevant correlation between asymmetry at the ventral electrodes and chronic stress remains unchanged (with efficacy beliefs included $sr = -.24$; with efficacy beliefs excluded $sr = -.23$, $p = .045$).

There was no significant indirect (mediation) effect of frontal EEG alpha asymmetry through self-efficacy beliefs on chronic stress experience (F7/F8; $b = .23$, SE = .546; Fp1/Fp2; $b = -.13$, SE = .608; F3/F4; $b = .59$, SE = .610). See Table 2 for all regression mediation results.

Behavioral measures of reappraisal inventiveness

A lower number of generated cognitive reappraisals (RIT-fluency) were associated with less left-lateralized activation at the ventral and most rostral electrodes during efforts to generate alternative appraisals (F7/F8; $sr = .20$, $p = .055$; $F(3,74) = 3.76$, $p < .001$; Fp1/Fp2; $sr = .25$, $p = .026$; F3/F4; $sr = -.25$, $p = .022$).

Levels of perceived chronic stress were not significantly predicted by the total number of generated cognitive reappraisals (RIT-fluency, $sr = -.10$, $p = .247$; $F(2,77) = 26.7$, $p < .001$). Looking closer into the categories of alternative appraisals, the number of responses categorized as positive re-interpretation showed a significant negative correlation with perceived chronic stress levels when efficacy beliefs in managing of emotions held constant ($sr = -.18$, $p = .038$; $F(2,77) = 29.3$, $p < .001$; zero-order correlation $r = -.14$, $p = .209$). No correlations were observed for responses categorized as problem-oriented ($sr = -.02$, $p = .809$; $F(2,77) = 25.7$, $p < .001$), de-emphasizing ($sr = -.02$, $p = .821$; $F(2,77) = 25.7$, $p < .001$), and revenge ($sr = -.05$, $p = .579$; $F(2,77) = 25.9$, $p < .001$). On average, $M = 5.1$ (SD = 3.9) responses were classified as positive re-interpretation, $M = 20.9$ (SD = 9.9) as problem-oriented, $M = 4.7$ (SD = 4.9) as de-emphasizing, and $M = 3.5$ (SD = 3.7) as and revenge.

Discussion

In the present study, women with higher chronic stress experience showed less left-lateralized brain activity in the ventrolateral prefrontal cortex during cognitive reappraisal efforts. Previous results in this research area had revealed that this activation pattern was associated with reduced inventiveness to generate suitable reappraisals for self-relevant, stressful situations (Papousek et al., 2017), a finding that was confirmed in the present study. Together, these findings nicely fit the notion that a more strongly left-lateralized activation in the ventrolateral prefrontal cortex during reappraisal efforts is more appropriate (efficient in terms of emotion regulation).

Correspondingly, in depressed as well as in elderly people showing reduced reappraisal success, attenuated activation in the left hemisphere or less left-lateralized activation was found in

Table 1. Prediction of perception of chronic stress by prefrontal EEG alpha asymmetries during efforts to generate cognitive reappraisals.

EEG alpha asymmetry at prefrontal electrode sites	r (p)	sr (p)
F7/F8 (ventral)	−.23 (.042)	−.24 (.006)
Fp1/Fp2 (most rostral)	.07 (.534)	.04 (.660)
F3/F4 (dorsal)	−.09 (.439)	.15 (.073)
Efficacy beliefs	−.63 (<.001)	−.64 (<.001)

Note: r = zero-order correlation, sr = semipartial correlation, p = p-value. Negative values of EEG alpha asymmetry denote higher alpha activity in the left than in the right hemisphere, that is, relatively lower left than right hemisphere cortical activity. Residualized scores adjusted for the asymmetry at the respective electrode site in resting conditions.

Table 2. Outcomes of mediation analyses from prefrontal EEG alpha asymmetry to chronic stress perception assessing indirect effects of perceived self-efficacy in dealing with negative emotions.

EEG alpha asymmetry			B			Bootstrap results for ab (95% CI)		Bootstrap results for ab sizes (95% CI)		
• Self-efficacy • Chronic stress	R^2	c' (p)	a (p)	b (p)	ab (p)	Lower	Upper	k^2	Lower	Upper
F7/F8 (ventral)	.44	1.77 (.021)	−.21 (.710)	−1.08 (<.001)	.23 (.712)	−.8875	1.3331	.0114	−.0345	.0894
• Self-efficacy • Chronic stress										
Fp1/Fp2 (most rostral)	.41	.75 (.333)	.12 (.835)	−1.09 (<.001)	−.13 (.836)	−1.4289	1.0138	−.0023	−.0330	.0162
• Self-efficacy • Chronic stress										
F3/F4 (dorsal)	.40	.17 (.823)	−.55 (.342)	−1.09 (<.001)	.59 (.348)	−.5344	1.9110	.0073	−.0102	.0744
• Self-efficacy • Chronic stress										

Note: B = unstandardized regression weight, c' = direct effect of predictor on outcome while controlling for the mediator, a = effect of the predictor on the mediator, b = effect of the mediator on the outcome, ab = indirect effect of predictor on outcome through the mediator, R^2 = amount of variance explained by the model, CI = confidence intervals; k^2 = effect size in kappa squared, p = p-value.

ventrolateral regions during cognitive reappraisal efforts (fMRI; Johnstone et al., 2007; Opitz et al., 2012). A recent review more generally indicated reduced recruitment of the ventrolateral prefrontal cortex during efforts to downregulate negative emotion in psychiatric disorders (Zilverstand, Parvaz, & Goldstein, 2017). The importance of left ventrolateral prefrontal activation is further corroborated by a number of imaging studies consistently showing increased activation in the left ventrolateral prefrontal region during instructed reappraisal, particularly at earlier periods of the experimental reappraisal phases that were presumably dominated by efforts to generate alternative appraisals (other activations also occur, which probably are related to other processes; Dillon & Pizzagalli, 2013; Kalisch, 2009; Ochsner et al., 2012; Phan et al., 2005). EEG alpha asymmetry studies, too, showed left-lateralized activation in the ventrolateral prefrontal region during efforts to generate cognitive reappraisals (Choi, Sekiya, Minote, & Watanuki, 2016; Papousek et al., 2017). This convergence across methods supports the basic assumption that relative decreases of EEG alpha power in one hemisphere indicate relative greater activation of that hemisphere, which has been questioned and may not hold in all instances (Miller et al., 2013). Importantly, cognitive reappraisal was shown to specifically recruit left ventrolateral prefrontal cortex when compared with other strategies such as expressive suppression or distraction (fMRI; Dörfel et al., 2014; Price et al., 2013). Note that while these findings converge in that they indicate the importance of left-lateralized activity in the ventrolateral prefrontal region, neither those findings nor the present results exclude that lateralized activity in other brain areas are also important or may even be more important for that matter.

The present findings also demonstrated that the effect of individual differences in brain activation during reappraisal efforts on chronic stress experience is also present when adjusting for individual differences in perceived efficacy in managing negative emotions. This corroborates the importance of the brain's basic capability to generate reappraisals for perceptions of chronic stress. The results suggested that both are important independently of each other: the brain's basic capability to generate alternative appraisals as well as the confidence that one's emotion regulation efforts are effective. This is in line with the suggestion that feelings of efficacy in managing negative emotions may be a necessary precondition to cope successfully with stressful events, because they make sure that individuals attempt to cope actively with stressful events, irrespectively of their abilities (Gohm et al., 2005). The formal size of the correlations might suggest that self-efficacy may play a much greater role than the basic foundation provided by the brain. However, the relatively high correlation between self-efficacy and chronic stress experience should not be over-estimated in this case, because it may partly be attributed to facet duplication or common method assessment (Freudenthaler & Papousek, 2013). Consequently, although confidence in one's own emotion regulation efforts is crucial in successfully dealing with negative emotions, one needs to account for the brain's basic capability to generate reappraisals when trying to understand practical ramifications of various emotion regulation strategies.

To the attentive reader, it might occur that the obtained individual differences in alpha asymmetry during the reappraisal task might have, in part, originated from the right-hand button presses shortly before participants vocalized their reappraisal ideas. There is evidence that repeated unilateral hand contractions may cause contralateral motor cortex activation to spread to prefrontal, particularly dorsolateral prefrontal cortex areas (F3/F4; Harmon-Jones, 2006; Peterson, Gravens, & Harmon-Jones, 2011; Peterson et al., 2008). However, the influence of motor preparation in tiny self-initiated finger movements such as single button presses on frontal asymmetry is less clear (e.g., Miller & Tomarken, 2001). Nonetheless, we had reduced the likelihood of possible influences of motor preparatory activity to a minimum by excluding the 450 ms preceding each button press from the EEG data analysis (cf. late Bereitschaftspotential; Shibasaki & Hallett, 2006). That as well as the fact that motor preparation predominantly influences activity at more posterior electrode sites rules out that participants' motor responses may have had decisively affected our results.

The importance of the individual's inventiveness in generating cognitive reappraisals is further substantiated by the correlation of lower chronic stress perception with higher scores on the behavioral test in terms of a higher number of generated positive re-interpretations. It is important to note

that reappraisal inventiveness in the RIT (Weber et al., 2014) refers to an ability measure in a narrower sense, as used in psychometrics (Cronbach, 1970), capturing what people can do at their best, thus reflecting the fundamental capacity for generating reappraisals rather than their typical behavior or typical achievement. While widely used in psychology (e.g., intelligence tests) as well as in neurology (e.g., motor performance tests) and psychiatry (e.g., neuropsychological testing), the use of maximum performance measures is largely novel to the field of cognitive reappraisal.

Certainly, this basic (brain) capacity for implementing cognitive reappraisals only covers a certain aspect of an individual's ability to effectively use cognitive reappraisal for negative affect regulation. At first glance, in daily life it might seem to be of even greater importance to produce one high-quality reappraisal than a pool of different appraisals to effectively mitigate the emotional impact of stressful situations. However, the ability to generate a variety of potential alternative appraisals for a given situation is one vital factor in the successful use of cognitive reappraisal. Individuals may rely on one or a few typical strategies for reappraisal that have become habitual over time and are sufficient until they are confronted with new situations, in which they cannot rely on their routine strategies. For effective emotion regulation, a broad repertoire of possible reappraisals and their flexible, situation-appropriate use is necessary. Thus, the effectiveness of reappraisal efforts depends in part on the pool of appraisals generated (see also Wisco & Nolen-Hoeksema, 2010). The capability to generate a broad pool of appraisals increases the individual's potential to select one that is most effective for successful coping with the specific stressful situation at hand.

In this study, there was a specific negative correlation between perceived chronic stress and the number of alternative appraisals categorized as positive re-interpretation. This suggests that, in addition to the general capacity to generate cognitive reappraisals, it may be the quality of the generated ideas that is critically related to emotional well-being. Research on the impact of different types of cognitive reappraisal has been sparse to date. The category of positive re-interpretation refers to situation-focused reappraisal, which aims at re-interpreting the nature of the emotional events themselves, thereby changing their meaning; as opposed to self-focused reappraisal, which involves altering the personal relevance of events (Ochsner et al., 2004). Experimental findings suggested that situation-focused reappraisal may be a more effective emotion regulation strategy than self-focused reappraisal, at least as reducing immediate negative responses to unpleasant stimuli is concerned (Willroth & Hilimire, 2016). Practicing reappraisal in terms of changing the meaning of a stimulus had more beneficial effects on later emotion regulation than practicing cognitive detachment strategies (Schartau, Dalgleish, & Dunn, 2009). In line with these empirical findings, cognitive reappraisal as used in psychotherapy typically focuses on re-interpreting the meaning of a stimulus (Dunn, Billotti, Murphy, & Dalgleish, 2009).

Interestingly, in two studies that instructed participants to use positive re-interpretation/situation-focused reappraisal, these strategies recruited a network comprising (left) lateral prefrontal cortex, while other brain regions were activated during attempts to reduce the personal relevance of emotional stimuli (Dörfel et al., 2014; Falquez et al., 2014). However, a meta-analysis of studies using various types of instructed reappraisal did not yield a clear picture on that matter (Webb et al., 2012), most likely because the analyzed studies had not specifically focused on differences between types of reappraisal, and thus no particular measures were taken to ensure that participants adhered to specific instructions. Again, it is important to note that it was the capability for positive re-interpretation that was negatively related to chronic stress experience in the present study, but not the self-reported typical use of this strategy, for which different relations might be found (e.g., Denny & Ochsner, 2014).

An important limitation of the present study is its correlational/cross-sectional design, which limits causal interpretations of the relations. While this study's research background suggests appropriate brain activation during cognitive reappraisal efforts being the cause and the perception of chronic stress the effect, reverse influences might also play a role. Effective implementation of cognitive reappraisal probably depends on the functionality of executive functions such as cognitive switching, memory updating, and the inhibition of dominant responses (Joormann & Gotlib, 2010; Malooly,

Genet, & Siemer, 2013; Pe, Raes, Kuppens, & di Pellegrino, 2013; Weber et al., 2014), which are linked to the recruitment of left prefrontal activation on their part (e.g., Badre & Wagner, 2007; Hirshorn & Thompson-Schill, 2006; Jahanshahi, Dirnberger, Fuller, & Frith, 2000; Jonides & Nee, 2006). There is some evidence that stress may impair core executive functions such as cognitive flexibility and cognitive (but not response) inhibition (Shields, Sazma, & Yonelinas, 2016). In line with this, animal research suggested that chronic stress increases synaptic inhibition onto prefrontal glutamatergic output neurons, thereby impairing the influence of the prefrontal cortex in controlling stress reactivity (McKlveen et al., 2016). It was suggested that these processes may foster attention to highly salient information (Vogel, Fernandez, Joels, & Schwabe, 2016), which may be beneficial for efficient threat responding, but may counteract the implementation of cognitive reappraisal, thus potentially initiating a vicious cycle.

Secondly, this study only included female participants. While a women-only sample was chosen to avoid confounding effects of sex differences in cognitive emotion regulation, this approach limits the generalizability of the findings. Further research is warranted to look into potential sex differences with respect to generating cognitive reappraisals for anger-eliciting events, both psychometrically and at the level of the brain. Another limitation of the present study is that the items in the cognitive reappraisal task concerned anger-evoking events only. Being a special case of negatively valenced and approach-oriented emotional states, more angry states have been linked to more left-lateralized activation in the prefrontal region (Harmon-Jones, 2004; Harmon-Jones, Gable, & Peterson, 2010; Stewart, Levin-Silton, Sass, Heller, & Miller, 2008). Hence, one might wonder whether the findings could perhaps be explained by individual differences in the experience of anger. However, if individual differences in anger experience had decisively influenced the results, they would indicate that greater experience/poorer regulation of anger was linked to less chronic stress perception. As poor regulation of anger is prospectively associated with higher perceptions of chronic stress and depression (Chue, Gunthert, Ahrens, & Skalina, 2017; Johnson et al., 2014; Naragon-Gainey & Watson, 2014), this seems very unlikely. Moreover, effects of anger on prefrontal EEG alpha asymmetry were typically observed at dorsal electrode sites (F3/F4; Harmon-Jones et al., 2010). Still, replication of the present findings with vignettes inducing emotional states other than anger is certainly required. Lastly, addressing the specificity of our findings, it must be emphasized that some specificity was demonstrated on the level of the brain, showing unique contributions of left-lateralized activity at the ventrolateral (but not other frontal) electrode positions during the generation of anger-reducing cognitive reappraisals in predicting chronic stress experience. Further research may expand the specificity issue by also including more posterior sites. On the behavioral level, more research will be required to identify which processes and aspects of well-being are most affected by the investigated brain process. There certainly may be considerable overlapping between chronic stress experience and other affective traits and disturbances.

Taken together, the present study demonstrated that women differ in their brain's proneness to recruit appropriate brain activation while attempting to generate cognitive reappraisals of stressful situations. These inter-individual differences seem to have sustainable effects on psychological well-being. The findings further suggest that if the brain's basic capability to generate alternative appraisals is impaired, reinforcing individuals' efforts to re-interpret stressful events alone may not suffice to impede or reverse stress-related psychopathological developments.

Disclosure statement

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