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PSYCHIATRY AND PRECLINICAL PSYCHIATRIC STUDIES - ORIGINAL ARTICLE

The differential relationship between trait anxiety, depression, and resting frontal α-asymmetry

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Abstract Relatively larger resting right frontal cortical brain activation has been labeled as a risk factor for emotion-related disorders. In light of this framework, the present studies' aim was twofold. First, we wanted to determine whether a relationship between symptoms of anxiety and depression and frontal asymmetry does already manifest in a sample of so far healthy individuals showing a large symptom range. This could be expected if frontal asymmetry constitutes a risk factor for depression and anxiety. Second, we aimed to investigate whether symptoms of depression and anxiety are independently related to frontal asymmetry, or whether either anxiety or depression is superior in predicting the relationship with frontal asymmetry. To address these questions, trait-like resting frontal α-asymmetry by means of EEG, as well as trait anxiety and depressive symptoms by questionnaire were measured from 43 healthy students (28 female). Results indicate that higher symptom severity of depression and anxiety were both significantly correlated with relatively larger right frontal cortical activation. However, in a regression analysis, frontal asymmetry was predicted by anxiety only. Controlling for depression and mood, anxiety explained 13% of variance, while controlling for mood and anxiety, depression did explain <1% of variance within frontal asymmetry. In conclusion, although both anxiety and depression add to the relationship, relatively larger right frontal cortical activity might be influenced more strongly by symptoms of anxiety. Moreover, as this effect is present already in healthy individuals, the findings might further support the notion that right frontal cortical asymmetry constitutes a risk factor for anxiety or depression.

Keywords Depression · Trait anxiety · Frontal cortical α-asymmetry · Hemispheric activation · EEG

Introduction

The approach-withdrawal model of hemispheric activation (e.g., Davidson 1992; Silberman and Weingartner 1986) suggests that left frontal brain areas mediate approach, while right frontal areas mediate withdrawal motivation. Based on this model, an atypical trait-like pattern of relatively larger right frontal cortical activation has been proposed as a general risk factor for the development of emotion-related disorders—including depression and anxiety (Coan and Allen 2004).[1] Within this framework, the present study aimed at investigating the differential relationship between symptoms of depression and anxiety with frontal asymmetry in a sample of healthy adult participants.

Indeed, reports supporting a link between these disorders and frontal cortical asymmetry are frequent. The vast majority of these studies found patients suffering from depression and anxiety to show relatively smaller left

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[1] Typically, asymmetrical frontal cortical brain activation is assessed by means of alpha power difference in electroencephalography between right and left frontal electrodes. Because cortical alpha power is inversely related to cortical activity (Davidson 1988), relatively enhanced right frontal cortical activity is indexed by relatively reduced right frontal alpha power, while relatively enhanced left frontal cortical activity is indexed by relatively reduced left frontal alpha power. Within the current manuscript we will refer to cortical activation rather than alpha power.

frontal/relatively larger right frontal cortical activation (for a metaanalytical review, see Thibodeau et al. 2006).[2] This association between trait-like resting frontal asymmetry and manifest anxiety and depressive disorders has been confirmed in numerous studies. However, in contrary, comparably few studies investigated the relationship between resting trait-like frontal asymmetry and symptoms of anxiety and depression in samples of healthy individuals (see Thibodeau et al. 2006 for a comprehensive review). Such a relationship would be expected if frontal asymmetry was a risk factor for the later development of depression or anxiety (c.f. Coan and Allen 2004; Nusslock et al. 2011; Koo et al. 2015). These studies yielded mixed results, with those confirming a relationship between symptoms of depression and/or anxiety, as well as studies yielding null findings (Thibodeau et al. 2006).

Moreover, the vast majority of studies (either assessing patient samples or healthy controls) investigated isolated symptoms of depression or anxiety, but not comorbidity. This is surprising, because comorbidity of anxiety and depression is very common (with rates of 50% or higher), involving greater symptom severity, weaker response rates to psychotherapy, and higher relapse rates (e.g., Wittchen et al. 2000). Moreover, significant subclinical symptoms of anxiety have been reported for the vast majority of patients suffering from depression, and vice versa (Gorman 1996; Kaufman and Charney 2000; Wittchen et al. 2000). Thus, the importance of comorbidity for the understanding of the clinical implications of brain asymmetry has been highlighted (Bruder et al. 1997; Heller and Nitschke 1998). However, of the few studies assessing comorbidity in clinical samples so far, two have reported no significant effects for frontal brain regions (Kentgen et al. 2000; Nitschke et al. 1999), one found reduced left frontal activation in the comorbid and depressed group (Mathersul et al. 2008), and one reported comorbid participants to show greater relative right-sided frontal activation as compared to controls (Bruder et al. 1997). Studies assessing depression and anxiety in healthy controls also yielded mixed results, with results supporting a link between both subclinical anxiety and depression (Blackhart et al. 2006; Wiedemann et al. 1999), as well as partial support for a relationship or even null findings (Tomarken and Davidson 1994; Nitschke et al. 1999). Moreover, most of these studies investigated female participants only, limiting generalizability of results (Thibodeau et al. 2006).

Thus, taken together, contrary to isolated disorders of depression or anxiety, the pattern of cortical asymmetry supporting comorbid symptoms of depression and anxiety in general and specifically in healthy individuals is still largely an open question. Taken together, to our knowledge, no study to date has been designed to evaluate whether symptoms of depression and anxiety share the same strength of relationship with frontal brain asymmetry in a sample of so far healthy female and male individuals using regression analysis. More precisely, given that depression and anxiety are highly comorbid, we aimed to determine whether depression and anxiety have the same predictive power to explain variance within frontal brain asymmetry, or if one is superior over the other in predicting frontal asymmetry.

Considering inconsistencies in the literature, the main aim of the current study was thus to determine whether (1) depression and anxiety are related to frontal brain asymmetry in a sample of female and male healthy participants showing a range of self-reported depression and anxiety and if (2) anxiety or depression is a better predictor of frontal brain asymmetry in a regression approach. Based on theoretical considerations (Coan and Allen 2004; Davidson 1992; Heller and Nitschke 1998), we await that greater resting right frontal brain asymmetry to be related to both self-reported depression and anxiety. However, if there is indeed a high co-existence between symptoms of anxiety and depression, then two outcomes of a regression approach are possible: (1) both symptoms of depression and anxiety are independently related to frontal asymmetry. This would cause both to significantly predict frontal asymmetry. (2) Either symptoms of depression or anxiety are related to frontal asymmetry, and symptoms of one would explain the association of the other. This would cause only symptoms of one of the both being a significant predictor of frontal asymmetry.

Materials and methods

Participants

Participants were 43 right-handed students ($n = 28$ female, age range 19–34 years, M = 24.2, SD = 3.8) recruited at Ruhr-Universität Bochum. Participants showed a large range of self-reported trait anxiety and depression (STAI-T score 23–61, M = 35.41, SD = 7.44, D-S sum score 0–19, M = 3.78, SD = 3.92). All participants reported no use of medication at the day of testing, and no current and no history of mental or neurological disorders. One participant decided to discontinue the experiment without giving a reason, and EEG data of one male and five female participants were lost due to technical reasons. The study was approved by the ethics committee of Ruhr-Universität

[2] However, as proposed by Hellers' two-dimensional model anxiety manifesting predominantly with symptoms of anxious-apprehension might also be characterized by enhanced relative left frontal activity (e.g., in generalized anxiety disorder) (Heller and Nitschke 1998; Nitschke et al. 1999).

Bochum. All participants gave written informed consent to procedures and were paid € 20 for participation.

Assessment of anxiety and depression

Anxiety was assessed with the trait form of the State-Trait Anxiety Inventory (STAI-T Laux et al. 1981), while depression was assessed with the Depressions Skala (D-S), a german depression questionnaire showing good psychometric properties and construct validity (c.f., D-S manual, von Zerssen and Koeller 1976), as well as high correlations with other self-rating measures of depression (Schmitt et al. 2003). It consists of 16 items assessing depressive symptoms, including, for example, dysphoric mood, loss of feelings, loss of energy, or suicidality, on a four-point scale. The STAI-T was chosen for reasons of comparability with the vast majority of previous research (see Thibodeau et al. 2006 for an overview). Both the STAI-T as well as the D-S showed good internal consistency in the actual sample (STAI-T: CR-$\alpha = .85$, DS: CR-$\alpha = .79$).

Psychophysiological recordings and response scoring

EEG data were recorded with a sampling rate of 1000 Hz using Ag/AgCl electrodes, digitized with 16 bit (BrainAmp, Brain Products, Germany) and filtered online with a 50 Hz notch filter. EEG was recorded according to the international 10/20 system from 32 scalp locations (Fp1, Fp2, F7, F3, Fz, F4, F8, Fc5, Fc1, Fc2, Fc6, T7, C3, Cz, C4, T8, Tp9, Cp5, Cp1, Cp2, Cp6, Tp8, P7, P3, Pz, P4, P8, Po9, O1, Oz, O2, and Po10) in reference to the left mastoid with impedances below 2 kOhm.

Offline, EEG channels were referenced to linked mastoids, high—(0.05 Hz, 24db/oct) and low pass filtered (40 Hz, 24 db/oct), and corrected for ocular artifacts (Gratton et al. 1983). Periods with excessive noise were excluded (i.e., amplitudes below −150 or above 150 μV, slopes >50 μV/ms). Frontal asymmetry was assessed in accord with published recommendations (see Allen et al. 2004). In brief, data were segmented in 2 s intervals (50% overlap) and Fast Fourier Transform was applied using a Hamming window (80%, end-tapered). Segments were averaged, and power density values in the alpha band (8–13 Hz) were extracted for each channel separately. Finally, an asymmetry score was calculated by subtracting right frontal activity from left frontal activity (i.e., lnF4–lnF3). Because cortical alpha power is inversely related to cortical activity (Davidson 1988), negative scores on this metric indicate relatively enhanced right frontal cortical activity, while positive scores indicate relatively enhanced left frontal cortical activity. We averaged across eyes open and eyes closed conditions; because both were highly correlated, $r = .83$, $p < .001$, Spearman Brown corrected reliability was .91 for the eyes open and eyes closed conditions, and averaging yields a more reliable estimate of frontal asymmetry than either condition alone (Hagemann 2004; Tomarken et al. 1992). Split half reliability between the first and second 4 min of data assessment of .98 indicates excellent reliability and suggests stability of measurement at least for our 8 min of data recording.

Data analysis

The main aim of the present study was to determine (1) if both symptoms of depression and anxiety are independently related to frontal asymmetry, or (2) if either symptoms of depression or anxiety explain the others' association with frontal asymmetry. Statistically, the first assumption would predict that both anxiety and depression will share a large amount of unique variance with frontal brain asymmetry (i.e., anxiety predicts asymmetry independent of depression and vice versa), while the amount of variance they share with frontal asymmetry together would be small. In contrary, the second assumption would predict that either depression or anxiety show a large amount of unique variance with frontal asymmetry alone (only depression or anxiety predicts asymmetry), while the others' relationship with frontal asymmetry is explained largely by the amount of shared variance of depression and anxiety with frontal asymmetry. To disentangle this relationship, we first conducted a hierarchical linear regression analysis. We included trait anxiety and depression as predictors and frontal brain asymmetry as dependent variable. Previous research suggests that changes in current states substantially influence resting frontal asymmetry (Hagemann et al. 2005; Coan and Allen 2004). Thus, to control for these influences, current mood (assessed with a modified version of the Self-Assessment Manikin, SAM, Bradley and Lang 1994) was entered as predictor in the first step, followed by trait anxiety (Step 2) and depression (Step 3). This analysis determines the total amount of variance added to the model at each regression step, and thus identifies the predictor which adds the largest amount of variance to the final model. However, during this procedure, shared variance between two predicting variables is assigned to the predictor entered into the model first. Thus, given the case that both depression and anxiety would both share a large amount of variance with frontal asymmetry, this method would assign it to the variable entered to the model first (in this case anxiety). Therefore, to determine the amount of variance depression, anxiety and mood uniquely share with frontal asymmetry and we report the partial correlations for the three predicting variables with frontal asymmetry (i.e., current mood, trait anxiety, and depression). With this approach, we are able to decompose

shared and unique variance of our predicting variables with frontal asymmetry (for details, see Cohen et al. 2003). By controlling for shared variance with the other predictors, this enables us to provide the variance uniquely contributed by the respective predictor.

Procedure

Upon arrival participants were seated in a recliner in a dimly lit room. Then, electrodes were attached and participants completed the mood questionnaire. Then, participants were instructed to relax with their eyes open (O) and closed (C) in one of two alternating orders of eight 1-min intervals (occococ or coococco), while resting EEG was recorded. After recording ended, participants completed the STAI-T and the D-S. Because the current study was part of a larger project, then an emotion perception task was conducted (data reported elsewhere). Afterwards, participants were paid for participation.

Results

Alpha-asymmetry scores were significantly negatively correlated with both scores of anxiety ($r = -.433$, $p = .007$) and depression ($r = -.330$, $p = .025$), indicating that relatively stronger right frontal cortical activation was associated with higher depression and anxiety scores (see Fig. 1).

Table 1 gives the results of the hierarchical regression analysis predicting frontal asymmetry with current mood, trait anxiety, and depression. Results show that entering current mood alone did not reveal a significant regression equation. Thus, frontal asymmetry could not be predicted by current mood alone. Entering trait anxiety in a second step resulted in a significant regression equation and a change of explained variance of about 26%. The beta weight for trait anxiety was significant, while the beta weight for current mood was significant at trend level only. However, adding depression in the third step did not improve the regressions model, and the beta weight for depression failed to reach statistical significance (see Table 1).

To assess the unique variance added by each predicting variable, we calculated partial correlations for each predictor with frontal asymmetry while controlling for shared variance with the other predictors. Figure 2 shows a graphical representation of the unique contribution of each predicting variable. In detail, controlling for depression and current mood, anxiety alone explained 13% variance in frontal asymmetry, $r = -.363$, $p = .032$, $R^2 = .132$. Controlling for anxiety and current mood, depression alone explained <1% variance in frontal asymmetry, $r = .062$,

Table 1 Hierarchical linear regression predicting frontal asymmetry from current mood, trait anxiety, and depression

Predictor	β	ΔR^2	F
Step 1		.001	$F(1,36) = 0.03$, $p = .855$
Mood	$.031^{n.s.}$		
Step 2		.259	$F(2,36) = 5.96$, $p = .006$
Mood	$-.329^{t}$		
Anxiety	$-.623^{*}$		
Step 3		.003	$F(3,36) = 3.92$, $p = .017$
Mood	$-.345^{t}$		
Anxiety	$-.717^{*}$		
Depression	$.101^{n.s.}$		

Newly entered variables are given in bold for each step; $^{n.s.}$ $p > .10$, ^{t} $p < .10$, * $p < .05$

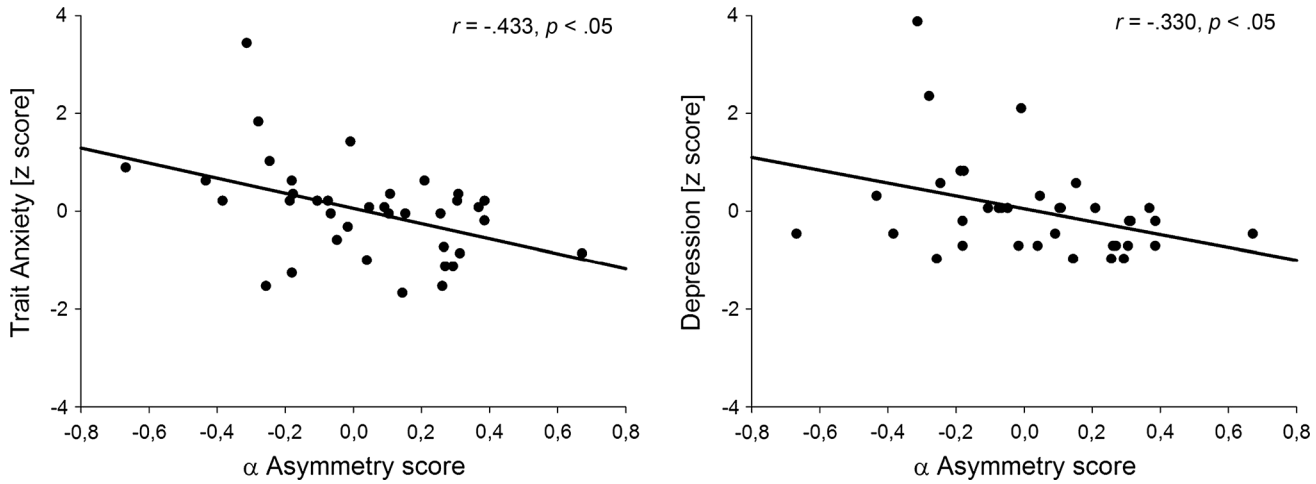

Fig. 1 Bivariate correlations between frontal alpha asymmetry score and anxiety (*left*) and depression (*right*)

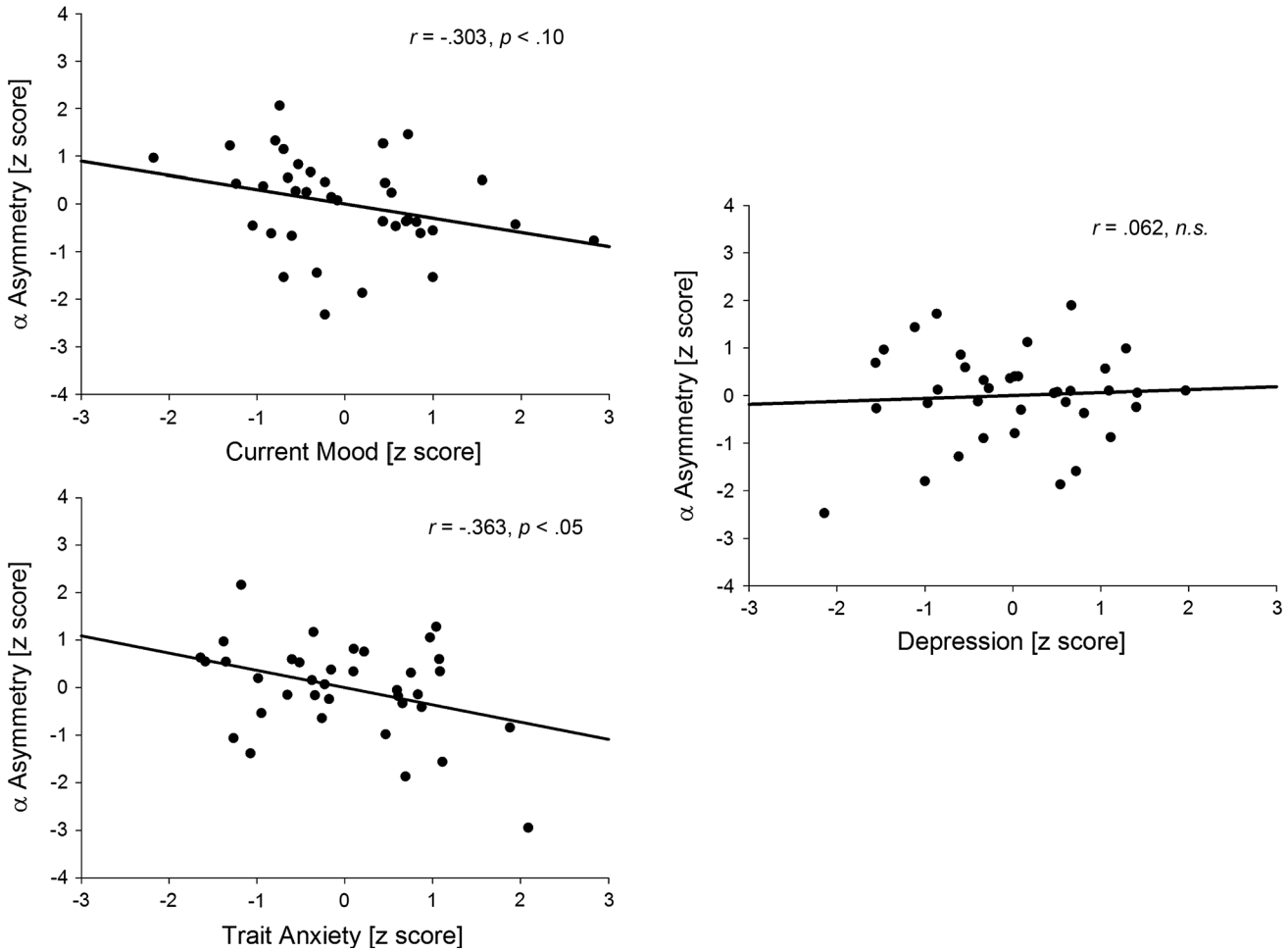

Fig. 2 Partial correlations between frontal alpha asymmetry score and current mood (*upper left*), trait anxiety (*lower left*), and depression (*right*)

$p = .723$, $R^2 = .004$. Controlling for anxiety and depression, current mood explained 9% of variance in frontal asymmetry, $r = -.303$, $p = .076$, $R^2 = .092$ (see Fig. 2).[3]

[3] In the current study we used a linked mastoid reference. This was chosen in favor of other classical reference schemes (i.e., average reference, vertex reference) because (1) it is favorable for the measurement of anterior alpha activity above the other schemes (Hagemann 2004) and (2) it has been widely used in research on frontal asymmetry (Hagemann 2004) and thus ensures comparability of results with previous literature. However, it was argued that a current source density measure (CSD) might be promising in order to avoid several reference issues such as mirroring of dipoles and others (Hagemann 2004)—also in context of resting trait-like frontal asymmetry (Velo et al. 2012; Stewart et al. 2010). Therefore, we also calculated the partial correlations determining the unique variance of our predicting variables depression and anxiety (our most important outcome measure) using the reference free CSD derivation (see Kayser and Tenke (2006) for methods). Results of these analyses were comparable with those from the linked mastoid reference. Controlling for mood and depression, anxiety significantly correlated with asymmetry, $r = -.370$, $p = .034$, while controlling for mood and anxiety, the correlation with depression failed to reach statistical significance, $r = .258$, $p = .147$ (no significant correlations were found for asymmetry scores including lateral frontal electrode sites, i.e., F7/F8, see for example Stewart et al. 2010).

Discussion

The present study aimed at testing whether a relationship between enhanced right frontal brain asymmetry and symptoms of depression or anxiety could be replicated in a group of healthy individuals and if both symptoms of anxiety and depression share the same strength of relationship with frontal brain asymmetry.

The current results confirm previous research indicating that both symptoms of depression and anxiety correlate with frontal brain asymmetry (reviews in Coan and Allen 2004; Thibodeau et al. 2006). In line with previous reports, more relative right frontal activation was associated with higher depression and anxiety symptom severity. The effect sizes of these correlations support a substantial association with frontal asymmetry for both symptoms of depression and anxiety, confirming robust effect sizes as reported previously (Thibodeau et al. 2006). Thus, the current data provide further support for a close link between frontal brain asymmetry and emotion-related disorders. Moreover, the current robust correlations between

anxiety and depression scores and right frontal cortical activation in a non-clinical sample of self-reported healthy young adults extend this work in showing that this relationship exist prior to the onset of a full blown mental disorder (c.f. Schaffer et al. 1983, for comparable findings with depressive symptoms) and has a predictive value for future symptom severity (Blackhart et al. 2006). The findings underscore the importance of frontal asymmetry as a marker for affective responding even in healthy populations (Davidson 1992).

In addition, the present study shows for the first time that in a direct comparison, higher trait anxiety but not depressive symptoms reliably predict relatively stronger right frontal brain activation in a regression approach. Importantly, our partial correlation analysis revealed that this effect is independent of current state-dependent mood, previously labeled a significant source of variance in frontal brain asymmetry (Hagemann et al. 2005). Moreover, we found that depression and anxiety share a large amount of variance with frontal brain asymmetry. This finding is in line with a wealth of previous reports (see Thibodeau et al. (2006) for a review). However, controlling for this shared variance left anxiety rather than depression to significantly predict frontal brain asymmetry (13% of variance explained). Thus, on the one hand, our data show that symptoms of anxiety, regardless of comorbid symptoms of depression are associated with relatively enhanced right frontal cortical activation, a pattern shown frequently in previous research (see Thibodeau et al. (2006) for a review). On the other hand—although paralleling prior findings of an association between frontal asymmetry with depression (overview in Allen and Reznik 2015)—the current data suggest that anxiety might be at least in part explaining the relationship between depressive symptoms and frontal brain asymmetry, leading to larger withdrawal motivation when symptoms of anxiety are present.

The current findings might, therefore, explain some inconsistencies in previous literature. Several studies showed relatively larger right frontal activation in depressed patients, while others have shown relatively reduced left frontal brain activation (see Thibodeau et al. (2006) for an overview). In most of these studies, comorbidity has not been reported. Thus, symptoms of anxiety rather than the depressive disorder per se might account for the higher right frontal asymmetry scores in prior studies. This assumption would be in line with a previous study demonstrating a correlation between larger relative right frontal activation and trait anxiety but not depression 1 year later (Blackhart et al. 2006). Moreover, our results match findings from epidemiological research showing that symptoms of depression and anxiety do frequently co-exist and comorbidity between the two disorders is highly prevalent. Moreover, retrospective data (Kessler et al. 1996) and longitudinal studies (Wittchen et al. 2000) have shown that in most cases, the anxiety disorder precedes depression, rendering anxiety the primary disorder increasing the risk for developing secondary depression. Taken together, it might be hypothesized that at least for a subgroup of patients with anxiety disorders, preceding depression larger relative right frontal brain activation might be either developing with symptoms of anxiety or vice versa. Both would lead to anxiety symptoms being predictive for relative right frontal brain activation in a regression approach.

Interestingly, recent source localization studies (Koslov et al. 2011; Pizzagalli et al. 2005) have shown that the dorsolateral prefrontal cortex (dlPFC) is the neural generator for resting frontal brain asymmetry (Davidson 2004). Thus, the current data are in accord with recent studies showing that resting state measures using functional magnetic resonance imaging found aberrant activity in dorsal attention networks, including the dlPFC (Liao et al. 2010; Anteraper Sheeba et al. 2014).

Of course, the current findings on comorbidity should nonetheless be interpreted with caution. Due to the focus of the present study, we did not recruit a clinical sample. Thus, we cannot rule out that the observed effects on comorbidity do not hold for a patient sample. However, nonetheless, the current sample shows a wide range of depression and anxiety (T scores 30–70) with some participants scoring well above the populations' mean for both depression and anxiety. In addition, in line with previous findings (Gold et al. 2013), correlational and regression analysis show a robust association of anxiety with frontal brain asymmetry. Moreover, it has previously been shown that relatively enhanced right frontal cortical activation predicts future depression in previously healthy people (Nusslock et al. 2011). Thus, although participants did not consist of diagnosed patients, a substantial number of patients should be at least considered at risk for emotional disorders.

Nonetheless, future research is needed to further explore the predictive value of the current data. Especially, it might be promising to consider the capability model to assess the differential relationship between anxiety, depression, and frontal brain asymmetry (see Coan et al. 2006) in healthy individuals. The model posits that individual differences in frontal asymmetry are best conceptualized as interactions between situational demands and the individuals' ability to respond to this situation (Coan et al. 2006). That is, rather than proposing that asymmetrical activation at rest would predict the individuals' withdrawal motivation within a specific situation, the model would predict asymmetrical activation within that situation to predict withdrawal behavior. With this approach, the relationship between situation-specific individual differences in frontal

asymmetry, emotional responding, and psychopathology could be investigated, enabling researchers to draw a more detailed picture of the predictive power of frontal asymmetry on the development of emotion-related disorders.

Conclusion

Taken together, the current data add to the body of literature arguing that frontal brain asymmetry might constitute a potential risk factor for the development of emotion-related disorders, such as anxiety and depression (e.g., Smit et al. 2007). Moreover, the, present study shows that although both depression and anxiety share a large amount of variance with frontal asymmetry, enhanced right frontal cortical activation might be predicted by anxiety rather than depression in a direct comparison. Thus, for future studies, it might be promising to include both measures of anxiety and depression to control for this shared variance (see also Jesulola et al. 2015).

References

Allen JJB, Reznik SJ (2015) Frontal EEG asymmetry as a promising marker of depression vulnerability: summary and methodological considerations. Curr Opin Psychol 4:93–97. doi:10.1016/j.copsyc.2014.12.017

Allen JJB, Coan JA, Nazarian M (2004) Issues and assumptions on the road from raw signals to metrics of frontal EEG asymmetry in emotion. Biol Psychol 67(1–2):183–218. doi:10.1016/j.biopsycho.2004.03.007

Anteraper Sheeba A, Triantafyllou C, Sawyer AT, Hofmann SG, Gabrieli JD, Whitfield-Gabrieli S (2014) Hyper-connectivity of subcortical resting-state networks in social anxiety disorder. Brain Connect 4:81–90. doi:10.1089/brain.2013.0180

Blackhart GC, Minnix JA, Kline JP (2006) Can EEG asymmetry patterns predict future development of anxiety and depression?: a preliminary study. Biol Psychol 72(1):46–50. doi:10.1016/j.biopsycho.2005.06.010

Bradley MM, Lang PJ (1994) Measuring emotion: the self-assessment manikin and the semantic differential. J Behav Ther Exp Psychiatry 25(1):49–59. doi:10.1016/0005-7916(94)90063-9

Bruder GE, Fong R, Tenke CE, Leite P, Towey JP, Stewart JE, Quitkin FM (1997) Regional brain asymmetries in major depression with or without an anxiety disorder: a quantitative electroencephalographic study. Biol Psychiatry 41(9):939–948. doi:10.1016/S0006-3223(96)00260-0

Coan JA, Allen JJB (2004) Frontal EEG asymmetry as a moderator and mediator of emotion. BiolPsychol 67(1–2):7–49. doi:10.1016/j.biopsycho.2004.03.002

Coan JA, Allen JJ, McKnight PE (2006) A capability model of individual differences in frontal EEG asymmetry. Biol Psychol 72(2):198–207. doi:10.1016/j.biopsycho.2005.10.003

Cohen J, Cohen P, West SG, Aiken LS (2003) Applied multiple regression/correlation analysis for the behavioral sciences. Lawrence Erlbaum, Mahaw

Davidson RJ (1988) EEG measures of cerebral asymmetry: conceptual and methodological issues. Int J of Neurosci 39:71–89. doi:10.3109/00207458808985694

Davidson RJ (1992) Anterior cerebral asymmetry and the nature of emotion. Brain Cogn 20(1):125–151. doi:10.1016/0278-2626(92)90065-T

Davidson RJ (2004) What does the prefrontal cortex "do" in affect: perspectives on frontal EEG asymmetry research. Biol Psychol 67(1–2):219–233

Gold C, Fachner J, Erkkilä J (2013) Validity and reliability of electroencephalographic frontal alpha asymmetry and frontal midline theta as biomarkers for depression. Scand J Psychol 54:118–126. doi:10.1111/sjop.12022

Gorman JM (1996) Comorbid depression and anxiety spectrum disorders. Depress Anxiety 4(4):160–168. doi:10.1002/(sici)1520-6394(1996)4:4<160:aid-da2>3.0.co;2-j

Gratton G, Coles MG, Donchin E (1983) A new method for off-line removal of ocular artifact. Electroencephalogr Clin Neurophysiol 55(4):468–484. doi:10.1016/0013-4694(83)90135-9

Hagemann D (2004) Individual differences in anterior EEG asymmetry: methodological problems and solutions. Biol Psychol 67(1–2):157–182. doi:10.1016/j.biopsycho.2004.03.006

Hagemann D, Hewig J, Seifert J, Naumann E, Bartussek D (2005) The latent state-trait structure of resting EEG asymmetry: replication and extension. Psychophysiol 42(6):740–752. doi:10.1111/j.1469-8986.2005.00367.x

Heller W, Nitschke JB (1998) The puzzle of regional brain activity in and anxiety: the importance of subtypes and comorbidity. Cogn Emot 12(3):421–447. doi:10.1080/026999398379664

Jesulola E, Sharpley CF, Bitsika V, Agnew LL, Wilson P (2015) Frontal alpha asymmetry as a pathway to behavioural withdrawal in depression: Research findings and issues. Behav Brain Res 292:56–67. doi:10.1016/j.bbr.2015.05.058

Kayser J, Tenke CE (2006) Principal components analysis of Laplacian waveforms as a generic method for identifying ERP generator patterns: I. Evaluation with auditory oddball tasks. Clin Neurophysiol 117:348–368

Kaufman J, Charney D (2000) Comorbidity of mood and anxiety disorders. Depress Anxiety 12(S1):69–76. doi:10.1002/1520-6394(2000)12:1+<69:aid-da9>3.0.co;2-k

Kentgen LM, Tenke CE, Pine DS, Fong R, Klein RG, Bruder GE (2000) Electroencephalographic asymmetries in adolescents with major depression: influence of comorbidity with anxiety disorders. J Abnorm Psychol 109(4):797–802. doi:10.1037/0021-843x.109.4.797

Kessler RC, Nelson CB, McGonagle KA, Liu J et al (1996) Comorbidity of DSM-III—R major depressive disorder in the general population: results from the US National Comorbidity Survey. Br J Psychiatry 168(Suppl 30):17–30

Koo PC, Thome J, Berger C, Foley P, Hoeppner J (2015) Current source density analysis of resting state EEG in depression: a review. J Neural Transm. doi:10.1007/s00702-015-1432-2

Koslov K, Mendes WB, Pajtas PE, Pizzagalli DA (2011) Asymmetry in resting intracortical activity as a buffer to social threat. Psychol Sci 22(5):641–649. doi:10.1177/0956797611403156

Laux L, Schaffner P, Glanzmann P, Spielberger CD (1981) Das state-trait angst angstinventar (STAI). Beltz Testgesellschaft, Weinheim

Liao W, Chen H, Feng Y, Mantini D, Gentili C, Pan Z, Zhang W (2010) Selective aberrant functional connectivity of resting state networks in social anxiety disorder. Neuroimage 52(4):1549–1558. doi:10.1016/j.neuroimage.2010.05.010

Mathersul D, Williams LM, Hopkinson PJ, Kemp AH (2008) Investigating models of affect: relationships among EEG alpha asymmetry, depression, and anxiety. Emotion 8(4):560–572. doi:10.1037/a0012811

Nitschke JB, Heller W, Palmieri PA, Miller GA (1999) Contrasting patterns of brain activity in anxious apprehension and anxious arousal. Psychophysiol 36(05):628–637. doi:10.1111/1469-8986.3650628

Nusslock R, Shackman AJ, Harmon-Jones E, Alloy LB, Coan JA, Abramson LY (2011) Cognitive vulnerability and frontal brain asymmetry: common predictors of first prospective depressive episode. J Abnorm Psychol 120(2):497–503. doi:10.1037/a0022940

Pizzagalli DA, Sherwood RJ, Henriques JB, Davidson RJ (2005) Frontal brain asymmetry and reward responsiveness: a source-localization study. Psychol Sci 16(10):805–813

Schaffer CE, Davidson RJ, Saron C (1983) Frontal and parietal electroencephalogram asymmetry in depressed and nondepressed subjects. Biol Psychiatry 18(7):753–762

Schmitt M, Beckmann M, Dusi D, Maes J, Schiller A, Schonauer K (2003) Messgüte des vereinfachten Beck-Depressions-Inventars (BDI-V). Diagnostica 49(4):147–156. doi:10.1026//0012-1924.49.4.147

Silberman EK, Weingartner H (1986) Hemispheric lateralization of functions related to emotion. Brain Cogn 5(3):322–353. doi:10.1016/0278-2626(86)90035-7

Smit DJ, Posthuma D, Boomsma DI, De Geus EJ (2007) The relation between frontal EEG asymmetry and the risk for anxiety and depression. Biol Psychol 74(1):26–33. doi:10.1016/j.biopsycho.2006.06.002

Stewart JL, Bismark AW, Towers DN, Coan JA, Allen JJB (2010) Resting frontal EEG asymmetry as an endophenotype for depression risk: sex-specific patterns of frontal brain asymmetry. J Abnorm Psychol 119:502–512. doi:10.1037/a0019196

Thibodeau R, Jorgensen RS, Kim S (2006) Depression, anxiety, and resting frontal EEG asymmetry: a meta-analytic review. J Abnorm Psychol 115(4):715–729. doi:10.1037/0021-843x.115.4.715

Tomarken AJ, Davidson RJ (1994) Frontal brain activation in repressors and nonrepressors. J Abnorm Psychol 103(2):339–349

Tomarken AJ, Davidson RJ, Wheeler RE, Kinney L (1992) Psychometric properties of resting anterior EEG asymmetry: temporal stability and internal consistency. Psychophysiol 29(5):576–592. doi:10.1111/j.1469-8986.1992.tb02034.x

Velo JR, Stewart JL, Hasler BP, Towers DN, Allen JJB (2012) Should it matter when we record? Time of year and time of day as factors influencing frontal EEG asymmetry. Biol Psychol 91(2):283–291. doi:10.1016/j.biopsycho.2012.06.010

von Zerssen D, Koeller D-M (1976) Paranoid-Depressivitäts-Skala/Depressivitäts-Skala PD-S/D-S. Hogrefe, Göttingen

Wiedemann G, Pauli P, Dengler W, Lutzenberger W, Birbaumer N, Buchkremer G (1999) Frontal brain asymmetry as a biological substrate of emotions in patients with panic disorders. Arch GenPsychiatry 56(1):78–84. doi:10.1001/archpsyc.56.1.78

Wittchen HU, Kessler RC, Pfister H, Höfler M, Lieb R (2000) Why do people with anxiety disorders become depressed? A prospective-longitudinal community study. Acta Psychiatr Scand 102:14–23. doi:10.1111/j.0065-1591.2000.acp29-03.x