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A B S T R A C T

Power density-ratios of fast and slow frequency spectrum-bands can be calculated from resting-state electroencephalography (EEG) recordings. A well-established phenomenon is that slow wave/fast wave ratios (SW/FW) are increased in attention-deficit/hyperactivity disorder. Several researchers have also begun to study relationships between SW/FW and affect. This work suggests that increased SW/FW may reflect reduced frontal cortical control over subcortical affective approach drive. The present study (n = 28) aimed to further examine this notion by testing several predictions derived from it. In line with these predictions, SW/FW was found to correlate negatively with fearful modulation of response inhibition in an emotional go/no-go task and with self-reported attentional control. Results also suggested a positive relation between SW/FW and trait approach motivation and a negative relation to anxiety, as predicted. These results are consistent with previous studies and support the notion that SW/FW may provide a useful tool in the study of affect and emotion regulation.

Spectrum analysis can be used to assess a resting-state electroencephalographic (EEG) signal in various conventional frequency bands. The β (beta) band (13–30 Hz) contains fast wave activity and δ (delta; 1–3 Hz) and θ (theta; 4–7 Hz) are slow wave bands. Differences in anterior cingulated cortex-generated θ activity have been related to affect and psychopathology (e.g., Mulert et al., 2007; Christie and Tata, 2009) and relations have been reported between different slow/fast wave measures and transient affect (Knyazev et al., 2005, 2006), motivational traits (Knyazev and Slobodskaya, 2003; Chi et al., 2005), performance on emotional–cognitive experimental tasks (Schutter and van Honk, 2005a), and endocrine measures and manipulations (Schutter and van Honk, 2004, 2005b; van Peer et al., 2008). Schutter et al. hypothesized that small slow/fast wave ratios (SW/FW) may predict anxiogenic (frontal) cortical downregulation of subcortically driven approach motivation and reward-seeking behaviour (see also Knyazev, 2007).

Several studies seem to corroborate this notion. Schutter and van Honk (2004) reported that a single administration of the fear-reducing and approach motivation-promoting hormone testosterone (e.g., van Honk et al., 2004; Tuiten et al., 2002; Hermans et al., 2008) increased frontal δ power, increasing δ/β ratio and diminishing the correlation between δ and β power. These authors also reported that higher SW/FW predicted more approach-driven and less risk-aversive motivated decision-making, suggesting that SW/FW may provide a useful tool to study emotional–cognitive interactions and psychopathology-related individual differences (Schutter and van Honk, 2005a).

The above suggests that SW/FW may be related to inhibition in response to motivationally relevant stimuli and emotional traits. The present study was designed to test various hypotheses in line with these general predictions to further investigate the proposed usefulness of SW/FW research for the study of emotion–cognition interactions and their relation to underlying biological functioning. In order to test if increased SW/FW predicts less fearful or inhibited and more reward-driven behaviour, we measured performance on an emotional go/no-go task. In a go/no-go task, participants are presented with different stimuli (here, pictures of fearful and happy faces) presented in succession on screen. They are instructed to respond as fast as possible to, for instance, a happy face, but to withhold response to a fearful face, or vice versa. These stimuli are termed ‘go’ and ‘no-go’ cues, respectively. Because a great majority (e.g., 75%) of the trials presents go cues, task performance is characterized by a predominant tendency to quickly respond and this primary tendency has to be inhibited on the no-go trials. Performance of this task, reflected in response times (RTs) and error patterns, reflects inhibitory control over approach-governed behaviour (Schulz et al., 2007). By examining the effect that the different facial expressions have on go and no-go trials, an index is obtained for the motivational modulation of behavioural approach and

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inhibition. However, ease of perceptual discrimination can vary for different facial expressions and is reportedly low for fearful faces (e.g., Goeleven et al., 2008). This will likely influence latencies of go/no-go responses, so RT analysis may then be replaced by a signal detection theory measure of response bias, beta (throughout the remainder of this paper, "beta" designates this measure for response bias, while the Greek character β refers to the 13–30 Hz EEG frequency band). Beta (based on probabilities of observed accuracy of performance) provides an estimate of more conservative or progressive response bias (see also Schulz et al., 2007). Fearful facial expressions serve as cues of danger and potential punishment, and so people will demonstrate stronger inhibition and inhibited response bias in reaction to fearful compared to happy faces in an emotional go/no-go task (Hare et al., 2005). The strength of cognitive and neural responses to fearful faces is often positively related to fear and anxiety (e.g., Rauch et al., 2000; van Honk et al., 2002; Fox et al., 2005; Putman et al., 2006). Also for the emotional go/no-go task it can thus be expected that more anxious (and anxiously inhibited) participants will demonstrate greater inhibitory modulation of go/no-go behaviour. The inhibitory control functions that govern go/no-go behaviour are to a large extent based in prefrontal cortical structures and for emotional modulation of go/no-go tasks, amygdala and lateral orbitofrontal cortex have been implicated additionally (e.g., Hare et al., 2005, 2008; Schulz et al., 2007). All in all, the emotional go/no-go task should provide a good experimental tool to study SW/FW and anxious (frontal) inhibition. We hypothesized that participants would demonstrate more inhibited responding to fearful than to happy faces, that this difference would be related to self-reported anxiety or inhibition, and that higher SW/FW would predict attenuation of this adaptive anxiogenic response pattern.

The abovementioned literature on SW/FW also suggests that SW/FW should predict stable affective traits. Specifically, SW/FW should correlate positively to reward-driven motivation and negatively to anxious and inhibited traits. We also hypothesized that SW/FW correlates negatively with a self-report measure of attentional control which is known to predict (inhibitory) attentional control in response to emotional stimuli and distracters (Derryberry and Reed, 2002; Bishop et al., 2007; Koster et al., 2008; Verwoerd et al., 2008; Putman et al., in review). These hypotheses were tested in a sample of healthy young women for comparison with previous studies (which tested only women; Schutter and van Honk, 2004, 2005a,b).

1. Methods

1.1. Participants

Twenty-eight right-handed, medication and drug free healthy young females were tested. Age ranged between 19 and 28 years with a mean of 22.7 (standard deviation = 2.6). Written informed consent was obtained and volunteers were paid for participation. The study was approved by the local review board.

1.2. Materials

1.2.1. Self-report measures

For motivational traits, the Carver and White Behavioural Inhibition and Behavioral Activation (BIS/BAS) scale (Carver and White, 1994) and the trait version of Spielberger's State-Trait Anxiety Inventory (STAI-t; Van der Ploeg et al., 1980; Spielberger, 1983) were used. The STAI-t questionnaire measures a single scale of trait anxiety. The BIS/BAS consists of a scale measuring behavioural inhibition (BIS), and behavioral activation (BAS), comprised of the sub scales BAS Reward, BAS Drive, and BAS Fun Seeking. To assess attentional control, the Attentional Control Scale (ACS; Derryberry and Reed, 2002; Verwoerd et al., 2006) was used. ACS and STAI-t scores are typically negatively correlated (see e.g., Derryberry and Reed, 2002; Bishop et al., 2007; Koster et al., 2008; Putman et al., in review).

1.2.2. Photo stimuli

Photos of facial expressions were selected from the Karolinska's Directed Emotional Faces (Lundqvist et al., 1998). Happy and fearful expressions from 10 male and 10 female actors were selected. Based on a recent validation study (Goeleven et al., 2008), actors with the highest recognition hit rate for fearful faces were chosen. Photos were presented as 9.5 (w) by 12.5 (h) cm rectangles.

1.2.3. EEG set up

EEG data were acquired with a Biosemi ActiveTwo system and digitized at a sampling rate of 256 Hz. Resting-state EEG was recorded with active Ag/AgCl electrodes on the F3, Fz, F4, C3, Cz, C4, P3, Pz, and P4 10/20 positions. Prior hypotheses concerned averaged frontal electrodes (c.f. Schutter and van Honk, 2004, 2005a); central and parietal recordings were done for unrelated and unreported investigative purposes. Electro-oculogram (EOG) was recorded with Ag/AgCl electrodes attached to the supra- and suborbital ridge of the left eye and on the external canthi of each eye. Common mode sense and driven right leg electrodes served as ground and EEG signals were offline re-referenced to the average of the left and right mastoid electrodes high- and low-pass cut-off frequencies were set at .1 and 100 Hz and amplification was set at 20,000 for all leads.

1.3. Procedures

Participants completed the emotional trait questionnaires at home, several days before the testing session. Resting-state EEG was measured in 8 alternating 1 min eyes open/closed recording periods (Allen et al., 2004). After the EEG measurement, participants filled out the ACS before cognitive performance testing.

1.3.1. Emotional go/no-go task

The emotional go/no-go task (EGNG) was programmed as an almost exact replication of the experimental procedure reported in Schulz et al. (2007). The only difference with that study concerns the choice of stimuli: presently happy and fearful faces were used instead of happy and sad faces. Either happy or fearful faces were designated as go and no-go cues in four alternating blocks (see Schulz et al., 2007). Each block presented 96 trials, 72 of which (75%) presented go cues and 24 trials (25%) presented no-go cues in semi-random order. Participants were first given opportunity to practice in two blocks of 8 'happy is go' and 8 'fearful is go' trials, with feedback on accuracy of their performance. Once it was determined that participants could perform the task, the experimental trials started. On each trial, a fixation cross was presented in the centre of the screen for a quasi-random duration of 1250–1750 ms (on average 1500 ms). Then, a face picture was presented for 500 ms. Participants could respond by pressing the down arrow key on the keyboard with the index finger of their right hand during presentation of a face or the subsequent fixation screen. They were instructed to respond to the go trials as fast as possible and to withhold responses to no-go trials, with repeated emphasis on fast responding.

1.4. Data reduction

1.4.1. EGNG data

False alarms (errors of commission) and hits (rightful responses to go cues) were calculated separately for happy = go and fearful = go conditions. For the correct responses to go trials, responses were discarded as slow outliers if RT > 1500. Remaining RTs were used to calculate mean RTs for happy = go and fearful = go conditions separately. For testing of perceptual sensitivity (d-prime) and response bias (beta), z-scores for proportionate hits and false alarms scores were calculated. A few participants had perfect scores in some conditions (proportionate false alarm scores and hit scores are then absolutely 0 or 1, for which z-values can not be given), so for all participants, false alarm scores were first increased with 1 and all hit scores were decreased with 1 before z-transformation. In this way, no data are lost and it is still possible to correlate individual differences in beta and d-prime with other measures. d-Prime was calculated as $z(\text{hits}) - z(\text{false alarms})$. Beta was calculated as $-\{[z(\text{hits}) + z(\text{false alarms})]/2\}$ (see Schulz et al., 2007). A lower d-prime indicates better perceptual sensitivity. For beta, a higher score indicates a more inhibited response bias. To analyze effect of expression condition on response bias, Expression Beta Contrast (EBC) was calculated as the difference between beta for fearful expressions minus beta for happy expressions. A higher EBC indicates a more inhibited response bias for fearful than happy expressions.

1.4.2. EEG data

Raw data were offline referenced to averaged mastoid sites, digitally low-pass filtered (35 Hz), and corrected for eye-movements (Gratton et al., 1983). Data of each minute of recording were subsequently segmented into segments of 4 s each with a 50% overlap. Segments containing residual muscle movements or other forms of artefacts, greater than $\pm 175\,\mu V$ were rejected prior to further analysis. All segments (eyes open and eyes closed) were collapsed for analysis A fast Fourier transform (Hamming window length 10%) was used to estimate spectral power density (μV^2) for frontal electrodes in the δ (1–3 Hz), θ (4–7 Hz), and β (13–30 Hz) frequency band (resolution 0.25 Hz). δ/β and θ/β EEG ratios were then calculated. Ratios were calculated by dividing slow wave power density by fast wave power density; i.e., θ/β and δ/β. Because of non-normal distribution, power density values and ratios were log-normalized. Finally, ratios for the three frontal leads were averaged to provide a single estimate of frontal SW/FW and the same was done for central and parietal recordings. For statistical tests, a two-tailed alpha of .05 was used unless explicitly stated otherwise.

Table 1
Mean power density values for the θ, δ, and β EEG frequency bands and θ/β and δ/β ratios, for the 9 recording sites separately. Higher ratio scores reflect relatively more slowly compared to fast wave power.

	F3	Fz	F4	C3	Cz	C4	P3	Pz	P4
θ	4.740	6.066	4.754	4.444	6.253	4.335	4.213	4.990	4.105
	(3.489)	(5.279)	(3.659)	(3.308)	(4.401)	(3.076)	(3.178)	(4.025)	(3.156)
δ	18.075	19.402	17.798	16.547	20.010	16.668	18.655	19.515	17.571
	(10.388)	(11.048)	(10.665)	(10.243)	(11.243)	(10.042)	(13.178)	(12.062)	(11.818)
β	.706	.720	.738	.671	.777	.692	.701	.779	.707
	(.320)	(.337)	(.320)	(.331)	(.377)	(.330)	(.342)	(.378)	(.340)
θ/β	7.143	9.134	6.882	7.471	8.901	6.972	6.542	6.897	6.243
	(3.886)	(5.776)	(4.013)	(4.776)	(5.274)	(4.319)	(3.855)	(4.240)	(3.752)
δ/β	28.739	31.070	26.817	29.289	29.768	27.973	29.913	28.478	27.936
	(15.705)	(17.508)	(14.275)	(19.099)	(16.630)	(16.600)	(18.228)	(16.223)	(16.345)

Table 2
Mean (SD in parentheses) RTs, total numbers of hits and false alarms (adjusted for z-transformation), d-prime, and beta values for the emotional go/no-go task ($n = 28$). Note that the false alarm score in the 'happy is go' condition represents the total number of erroneously executed key presses when a fearful face was presented as a no-go cue and vice versa for 'fearful is go'.

	RT	Hits	False alarms	d-Prime	Beta
Happy is go	453 (57)	142.39 (1.59)	8.04 (4.23)	−2.89 (.36)	.54 (.20)
Fearful is go	487 (67)**	142.21 (2.02)	10.82 (4.91)**	2.64 (.36)**	.66 (.21)*

* $p < .005$.
** $p < .001$.

2. Results

2.1. Self-report measures—emotional traits and attentional control

An expected significant positive correlation was found between STAI-t and BIS ($r = .753$; $p < .001$). There was an expected negative correlation for ACS and STAI-t ($r = -.358$; $p = .031$; one-tailed). BAS Drive was positively correlated to θ/β ratio ($r = .430$; $p = .022$) as expected. No other significant bivariate correlations were observed. Since STAI-t and ACS were expected to both correlate negatively to θ/β ratio while a negative correlation was also expected between these two predictors, partial correlations between θ/β ratio and the one, controlling for the other were calculated. When controlling for ACS, the negative partial correlation between STAI-t and θ/β ratio was $r = -.386$; $p = .047$. Note that these p-values are not corrected for multiple testing and correlations to a total of five emotional self-report measures were tested. The ACS was negatively correlated to θ/β ratio ($r = -.395$; $p = .037$) as expected; when controlling for STAI-t, the negative partial correlation was $r = -.505$; $p = .007$.

2.2. EEG measures

Table 1 provides mean power density measures for θ, δ, and β, and θ/β and δ/β ratios for all electrodes. As can be seen, SW/FW ratios tend to be greater for midline compared to lateral recordings, specifically for more anterior recordings. Also, θ/β ratios tend to decrease from frontal to parietal recordings.

2.3. Emotional go/no-go

See Table 2 for a summary of EGNG data. Correct responses to happy go cues were made faster than to fearful go cues, as expected ($t(27) = 5.65$; $p < .001$; $d = .55$). As expected, participants were more likely to respond with a false alarm to happy cues than to fearful cues; $t(27) = 3.60$; $p = .001$; $d = .61$). Comparison of d-prime scores showed that happy faces were also discriminated better than fearful faces: $t(27) = 3.84$; $p = .001$; $d = .69$. Finally, beta was greater for fearful faces than for happy faces ($t(27) = 3.2$; $p = .004$; $d = .59$), indicating a more inhibited response bias toward fearful than happy faces, as predicted. Because of the strong d-prime difference between the face-types (demonstrating differential discriminability), only beta-derived EBC scores are related to self-report measures and EEG ratios below.

As hypothesized, STAI-t was significantly correlated to EBC ($r = .395$; $p = .046$) indicating more relative inhibition on fearful cue trials than on happy cue trials in the more anxious subjects. Contrary to expectation, there was no correlation between BIS and EBC ($r = .133$; $p > .1$). EBC scores were negatively correlated to δ/β ratio ($r = -.435$; $p = .021$) and θ/β ratio ($r = -.443$; $p = .018$), indicating that subjects with higher ratios demonstrated attenuated relative inhibition in response to fearful as compared to happy faces, as hypothesized (Fig. 1).

2.4. Locality

To assess spatial specificity of the most important relations between SW/FW and outcome measures, correlations for θ/β ratios based on separate frontal and averaged frontal, central and parietal

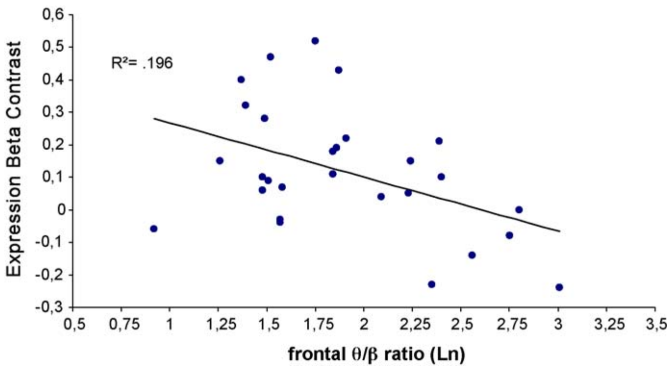

Fig. 1. Scatterplot for the relation between log-normalized frontal θ/β ratio and the expression beta contrast (EBC). Higher EBC score indicates greater relative inhibition to respond to fearful compared to happy go cues. The negative relation depicted here shows that increased θ/β ratio predicts less fearfully inhibited emotional go/no-go behaviour.

Table 3
Pearson's correlation coefficients between the most relevant outcome measures and θ/β ratios derived from the averaged frontal, central, and parietal recordings. The corresponding p-value is given between parentheses. N = 28.

	Frontal	Central	Parietal
BAS Drive	.430 (.022)	.445 (.018)	.448 (.017)
ACS	−.395 (.037)	−.376 (.048)	−.265 (.173)
EBC	−.443 (.018)	−.363 (.058)	−.314 (.104)

recordings were post hoc compared. Table 3 provides an overview of these correlations.

Averaged frontal and central recordings provide very similar correlations that do not differ significantly according to Steiger tests for comparison of dependent correlation coefficients (largest t = 1.64). Although the correlations between parietal θ/β ratio and two of the three outcome measures are non-significant, only for the relation between θ/β ratio and ACS was there a significant difference, with the central recording showing a stronger correlation than the parietal recording ($t(25) = 2.67$; $p = .013$). Thus, sagittal locality seems to matter very little, with apparently stronger correlations for more anterior recordings, but the differences are small and mostly statistically insignificant.[1]

2.5. Influence of age

Also relations involving age were checked. This showed firstly a very strong negative relation between age and θ/β ratio ($r = -.673$; $p < .001$) and a negative relation between age and δ/β ratio ($r = -.466$; $p = .012$). Also the relations between age and BAS Drive, ACS, and EBC score were significant, with coefficients very similar (inverse) to the relations between these measures and θ/β ratio. For BAS Drive a negative correlation with age was $r = -.431$; $p = .022$, for ACS, a positive correlation with age was $r = .414$; $p = .028$, and for EBC score, a positive correlation was $r = .429$; $p = .023$. In order to control for the possibility that age might mediate relations between θ/β ratio and the relevant outcome measures (emotional trait, attentional control, and EBC), post hoc separate hierarchical regression analyses were performed with the outcome measures as dependent variables, θ/β entered as predictor in the first block, and age entered in the second block. For none of the outcome measures did these analyses show mediation (adding age never explained significantly more variance and all partial correlations were non-significant; smallest $p = .246$).

3. Discussion

Results confirmed a hypothesized negative relation between SF/FW and inhibited performance on an emotional go/no-go task. Also as predicted, it was found that a self-report measure of attentional control correlated negatively to θ/β ratio. Suggestive but less convincing evidence was found for a hypothesized positive relation between θ/β ratio and reward-oriented motivational trait and for a hypothesized negative correlation between θ/β ratio and trait anxiety. An inverse relation was found between age and SF/FW and age unexpectedly predicted these outcome measures with similar (but mirrored) correlations. These results and their interpretation are discussed in more detail below.

Schutter and van Honk (2005a) reported that increased SW/FW predicted perseverance of a non-adaptive, reward-driven and punishment-insensitive performance pattern on a motivated decision-making task (the IGT; Bechara et al., 1996). This maladaptive perseverant choice pattern may result either from reduced/increased sensitivity to cues of punishment/reward, or from a failure to adequately utilize these cues to learn to inhibit a maladaptive appetitive response. Therefore, we presently tested behaviour on an emotional go/no-go task which more directly reflects inhibition of such motivational cues. Prior expectations were that healthy participants would demonstrate inhibited responses to fearful face cues. This was confirmed. Analyses showed slower responses to fearful as compared to happy go trials as well as reduced numbers of false alarm errors in response to fearful faces, both suggesting inhibited responses to fearful faces. However, error pattern analysis showed that subjects also demonstrated increased perceptual sensitivity for happy compared to fearful faces. Analysis of beta scores confirmed that subjects responded in a more inhibited manner to the fearful compared to the happy faces (see also Hare et al., 2005). Also, as expected, this relative inhibition toward fearful faces was positively related to trait anxiety levels. This confirms that the relative response inhibition to fearful faces, defensibly a (phylogenetically) adaptive response (Öhman, 1986; Hare et al., 2005, 2008), is also related to individual differences in affect and suitable to study individual differences in affect-related cognitive performance and brain processes. The EBC contrast, reflecting this more inhibited response to fearful cues, was indeed negatively correlated to both slow/fast wave ratios. This is compatible with the notion put forth by Schutter et al. that increased SW/FW may reflect reduced anxious cortical control over subcortically driven approach tendencies (Schutter and van Honk, 2004, 2005a,b) and concurs with the finding in the present data that SW/FW may correlate negatively to self-reported anxiety.

This study also explored the notion that high SW/FW may be related to reward- and approach related motivational traits as measured with validated self-report instruments. Contrary to expectation, there was no relation between SW/FW and BAS Reward and BAS Fun Seeking. There was a significant correlation between the θ/β ratio and the BAS Drive subscale (a motivational trait that is related to motivated cognitive performance and prefrontal cortical regulation of subcortical response to facial signals of social threat, for instance; Putman et al., 2004; Beaver et al., 2008; Passamonti et al., 2008). However, multiple correlation tests for motivational traits were performed and this correlation would not withstand a stringent alpha-correction, possibly due to limited statistical power in our sample size. As such, these results for the approach-trait hypothesis are inconclusive.

It was also studied if measures of anxiety and anxious inhibition would show a negative correlation to SW/FW. ACS scores are commonly reported to considerably co-vary with anxiety scores (see e.g., Derryberry and Reed, 2002; Bishop et al., 2007; Putman et al., in review), as was the case in the present sample. When we controlled for ACS, higher trait anxiety did indeed predict lower θ/β ratio. However, BIS (a similar and correlated construct for anxious inhibition), did not correlate significantly to SW/FW and so also the significant relation to trait anxiety is subject to the problem of multiple testing. All in all, some expectations concerning affective traits were met, but follow-up research in greater samples or utilizing fewer measures of emotional traits should attempt to replicate these findings before strong conclusions can be drawn.

As predicted, attentional control was negatively correlated to θ/β ratio, specifically when controlling for trait anxiety (which is negatively correlated to ACS scores but is expected to be similarly related to SW/FW). The ACS measures self-reported ability to focus and shift attention and has been related to biased cognitive processing of threat-related stimuli (Derryberry and Reed, 2002; Putman et al., in review). Bishop et al. (2007) examined relations between anxiety and prefrontal cortical responses to distracting

[1] It was also explored if correlations between θ/β and outcome measures were similar for the three frontal positions (for all nine correlations, $|r| \geq .353$; $p < .07$). This showed that laterality of frontal recordings seems largely negligible, with only minor indications that midline recordings might be related more strongly to outcome measures than lateral recordings.

fearful faces. Results showed reduced PFC activity in response to fearful distracters and this effect was moderated by ACS scores. These authors interpreted their data as possibly reflecting that ACS predicts recruitment of PFC efforts to inhibit processing of distracting fearful faces. In the present study, ACS scores inversely predicted the EEG ratios that have been suggested to perhaps reflect cortical–subcortical interaction (Schutter and van Honk, 2004, 2005a,b; Knyazev, 2007). The correlation between ACS scores and SW/FW seems also in line with the often made observation of increased SW/FW in people diagnosed with Attention-Deficit/Hyperactivity Disorder (ADHD) which is associated with impulse control problems and reduced control of attentional functions, probably as a result of dysfunction of prefrontal cortex (PFC; e.g., Brennan and Arnsten, 2008). Aberrant SW/FW in ADHD is normalized by administration of stimulants, the drugs of choice in ADHD treatment which probably restore adequate inhibitory control via dopaminergic facilitation of prefrontal cortical functioning (Clarke et al., 1998, 2007, 2008; Bresnahan et al., 1999, 2006; Snyder and Hall, 2006). The presently found relation between ACS and θ/β is interesting for several reasons. First, since attention and attentional control are generally thought to be prefrontal functions (e.g., Brennan and Arnsten, 2008), and since Bishop et al. (2007) directly linked ACS score to PFC involvement in regulation of subcortically driven responses to fearful faces, these self-report data, like the go/no-go data, provide some indirect support for the notion that SW/FW may reflect cortical–subcortical interactions. Secondly, the concept of attentional control and the use of the ACS scale for its measurement are currently receiving increasing interest in the field of developmental (e.g., Muris et al., 2003), emotional–cognitive (e.g., Koster et al., 2008; Verwoerd et al., 2008; Putman et al., in review), and emotional–neuropsychological literature (e.g., Mathews et al., 2004; Bishop et al., 2007). The present data demonstrate the potential usefulness of θ/β ratio as a psychophysiological correlate in future research studying attentional control.

Somewhat unexpectedly for our fairly typical post-adolescent student sample, age (ranging between 19 and 28 years) proved to be strongly related to SW/FW and it predicted outcome variables in a comparable (mirrored) manner as SW/FW. Mediation analyses reassured that relations between SW/FW and the outcome variables were not dependent on age, but rather the data suggest that age and SW/FW to a considerable extent reflect the same underlying factor of maturational differences. The finding of increased SW/FW in children and adolescents with ADHD has been interpreted as reflecting a 'maturational lag' in (frontal) brain development (e.g., Clarke et al., 1998; Bresnahan et al., 1999). Normal maturation increases fast wave activity and reduces slow wave activity (see also Clarke et al., 2002). Bresnahan et al. reported a decline of θ/β ratios between healthy adolescent and adult groups with a mean age of 14.3 and 32.5 years, respectively. It is tempting to speculate that the present findings are related to a developmental improvement in affect regulation based in increased PFC function. Note that Knyazev (2007) in his review of EEG spectrum analysis and affect takes increasing cortical maturation and accompanying increase of fast wave power as a prior argument for the hypothesis that analysis of EEG spectral power may be useful to study affect regulation. However, the present study was not designed to address this issue and it seems unwise to speculate that the present findings partially reflect maturation of the PFC. Participants in our sample were 19 years and older and there is presently no consensus if the brain, and in particular the (frontal) cortex, continues to substantially develop after adolescence (see e.g., Gogtay et al., 2004). Still, such a potential relation between post-adolescent SW/FW and ongoing maturation may be critically considered in discussion on the usefulness of SW/FW analysis as a tool to study individual differences and psychopathology.

Based on previous research (Schutter and van Honk, 2004, 2005a), we primarily looked at frontal recordings. Eye-ball inspection may suggest that θ/β ratios derived from more anterior electrodes give overall the strongest correlations for the predicted relations. However, these differences between frontal, central, and parietal recordings were small and only one correlation proved significantly weaker for parietal compared to central recordings. All in all then, these data suggest that relations between SW/FW and affective variables are not only specific to frontal sites, but also apply to more posterior, at least also to central, locations.

Limitations to this study are, first, that only females were tested and it is not known how gender might influence the results. Secondly, as a first exploration of our hypotheses concerning self-reported motivational traits, multiple measures were used. Although several reliable relations to the EEG data were found (in isolation), strong conclusions are presently not possible due to the chance-capitalization problem that this explorative approach introduced into the design. However, these trait findings are suggestive enough to warrant more closely targeted follow-up research.

In summary, the present results verify and extend previous suggestions that SW/FW may be used to study affect and emotional–cognitive performance. Negative relations between SW/FW and expression-specific response bias in the emotional go/no-go task and self-reported levels of attentional control are at least consistent with the hypothesis that increased SW/FW may reflect reduced frontal cortical functions. Results for self-reported affective traits were somewhat inconclusive but do seem to verify the idea that increased SW/FW relates to greater reward- and approach-driven affect and reduced anxiety.

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