Losing control : anxiety and executive performance

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Chapter 2

EEG theta/beta ratio as an electrophysiological marker for attentional control and its test-retest reliability

ABSTRACT

A robust finding is that resting-state frontal theta/beta ratio (TBR), a spontaneous electroencephalographic (EEG) frequency band parameter, is increased in attention-deficit/hyperactivity disorder. Accumulating evidence suggests that TBR might also provide an objective marker of executive cognitive control (and more specifically attentional control; AC) in healthy adults. The present study aimed to further investigate this conception by assessing EEG frequency band power and AC twice (with a one-week interval) in 41 young female adults. In line with our predictions, the negative association between TBR and trait AC, as measured with an often used self-report measure, was replicated. Results also demonstrated that test-retest reliability of resting-state frontal TBR was very good (r = .93) and, moreover, TBR measured at the first session predicted AC during the second session (r = -.44). These consistent results further reinforce the notion that frontal TBR could be used as a reliable biomarker for prefrontally-mediated executive AC.

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Biological psychology. 2016 Dec 1;121:49-52.

INTRODUCTION

There is increasing interest in slow wave/fast wave (sw/fw) spectrum measures for spontaneous electroencephalography (EEG) in relation to individual differences in cognitive control and emotional processing (Knyazev, 2007; Massar et al., 2014; Putman et al., 2014; Sari et al., 2015; Schutter & Knyazev, 2012; Tortella-Feliu et al., 2014). Spontaneous theta/beta ratio (TBR), the ratio of theta band (4-7 Hz) power divided by beta band (13-30 Hz) power, is argued to reflect cortical-subcortical interactions (Arns et al., 2013; Schutter and Van Honk, 2005) and accumulating evidence indicates that it might be a promising biomarker for prefrontally-mediated executive control functions, most notably attentional control (AC).

AC is suggested to be regulated by two reciprocal systems; a bottom-up system, instigating the detection and engagement of salient stimuli, which is carried out by anterior cingulate cortex (ACC) and subcortical areas such as the thalamus and amygdala (Bishop, 2008; Hermans et al., 2014), and an intentional top-down system, responsible for maintaining attention to task-relevant information mediated by (dorso-) lateral prefrontal cortex (dlPFC; Bishop, 2008; Fani et al., 2012; Gregoriou et al., 2014). Numerous studies have demonstrated that TBR is elevated in attention deficit/hyperactivity disorder (ADHD) and in the predominantly inattentive subtype of attention deficit disorder (ADD; Arns et al., 2013). In addition, psychostimulants which increase PFC network integrity normalize TBR and reduce ADHD symptoms (Arnsten, 2006; Clarke et al., 2002; Clarke et al., 2007). Since ADHD symptoms likely stem from (frontal) cortical hypoarousal and subcortical hyperarousal (Barry et al., 2003; Lubar, 1991), the ADHD-TBR literature strongly supports the idea that TBR might reflect frontal cortical regulation of subcortical processes. Recent years have seen an increasing interest in TBR in healthy adults. Studies have reported, for instance, a negative relationship between TBR and trait AC as well as stress-induced AC decline (Putman et al., 2010b; 2014), attentional orienting (Morillas-Romero et al., 2015b), emotion regulation (Tortella-Feliu et al., 2014), behavioral inhibition (Putman et al., 2010b) and motivated decision making (Massar et al., 2014; Massar et al., 2012), all in healthy adults.

In the present study, we aimed to replicate the cross-sectional negative relationship between frontal TBR and self-reported AC (hypothesis 1). Moreover, to further explore the potential usefulness of TBR as a biomarker for prefrontal executive control function we measured TBR and AC in two separate sessions, separated by one week, allowing the first assessment of TBR's test-retest reliability (hypothesis 2) and its ability to predict AC (hypothesis 3). We also included measures of trait anxiety to control for possible confounding relationships (c.f. Putman et al., 2010b; 2014).

METHODS

Participants

Forty-one healthy female participants (for practical reasons) from Leiden University campus were tested. Participants were screened for use of psychoactive medication, and written informed consent was obtained. After participation, two participants were excluded for use of psychoactive medication. Age ranged between 18 and 31 (M = 21.2, SD = 2.9). Participation was compensated with course credits or a small monetary reward. The study was approved by the local review board.

Apparatus and Materials

Self-report measures Trait anxiety was assessed with the trait version of Spielberger's State-Trait Anxiety Inventory (STAI-t; Spielberger, 1983; Van der Ploeg et al., 1980). The Attentional Control Scale (ACS; Derryberry & Reed, 2002; Verwoerd et al., 2006) was used to assess attentional control.

EEG recording and data reduction For a full description, see Putman et al. (2014). We analyzed the average area power densities of the frontal electrodes (Fz, F3, F4). Non-normally distributed power densities and TBR values were normalized (natural log transformed, Ln) before statistical hypothesis testing.

Procedure

Participants were invited to the same lab twice with an one-week interval. On both sessions, participants first completed the questionnaires, followed by the baseline EEG measurement.

RESULTS

Table 1 and 2 provide descriptives, correlations, and t-tests comparing all the measurements between the two sessions, as well as the correlations between these measurements during both sessions, respectively.

Data reduction

One participant was excluded from analyses as an outlier (score more than 2.5 SD above the group mean) for Ln-normalized beta power density during the first session. Next, Mahalanobis distance revealed a significant bivariate outlier for the relationship between TBR and ACS (D^2 = 11.20, p < .005) which was removed from relevant analyses (results were very similar for the original sample).

Self-reported measures

As commonly reported (e.g., Bishop et al., 2007; Derryberry & Reed, 2002; Putman et al., 2014), significant negative correlations were found between ACS

and STAI-t. STAI-t scores did not differ between the two sessions but ACS scores were lower in the second session. Test-retest reliability of ACS and STAI-t were very high (see Table 1).

TBR and AC

Significant negative correlations were found between frontal TBR and ACS in both sessions. Moreover, TBR in both sessions correlated with ACS scores of contrasting sessions (see Table 2; Fig. 1). These correlations remained significant after controlling for STAI-t (weakest correlation $r < -.39$, $p = .02$; cf. Putman et al., 2010b).

Test-retest reliability

Test-retest reliability of TBR was very high ($r = .93$) even though TBR was higher during the second session (Fig.1). Post-hoc t-tests suggest that the increase of TBR in the second session was due to increase of theta power (see Table 1).

Age

Associations of age with TBR and ACS were also tested as they have been previously reported by Putman et al. (2010b). Since log-normalized age was still not normally distributed, Spearman's correlations were conducted. A negative association between age and TBR ($r_s = -.40$, $p = .014$; $r_s = -.38$, $p = .02$, for the first and the second session respectively) was found. There was no significant relation between age and ACS ($r_s = .04$, $p = .812$; $r_s = -.01$, $p = .949$, for the two sessions). The negative relationship between TBR and ACS for both sessions remained significant after controlling for age (weakest correlation $r = -.41$, $p = .014$; c.f. Putman et al., 2010b).

Table 1. Means (and standard deviations) for self-report and frontal EEG data of both sessions ($n = 38$).

	TBR	Theta power	Beta power	ACS	STAI-t
Session 1	1.161 (0.531)	12.926 (6.078)	11.903 (4.417)	55.2 (8.5)	37.2 (7.4)
Session 2	1.272 (0.589)	14.703 (7.258)	12.404 (4.764)	54.0 (8.6)	36.4 (7.9)
r	.93***	.94***	.90***	.91***	.92***
t	-3.22**	-4.67***	-1.14	2.18*	1.42
d	.52	.76	.19	.35	.23

Note: reported descriptives of frontal TBR, theta power, and beta power are not Ln-normalized for more intuitive appreciation and comparability with other studies. *$p < .05$, **$p < .005$, ***$p < .001$

Table 2. Pearson correlation coefficients between group characteristics during both sessions (n = 38 apart from the relationship between TBR and ACS where n = 37).

		TBR		ACS		STAI-t	
	Session	1	2	1	2	1	2
TBR	1	-					
	2	.93***	-				
ACS	1	-.47**	-.44**	-			
	2	-.44**	-.37*	.91***	-		
STAI-t	1	.11	.07	-.57***	-.59***	-	
	2	.09	.04	-.54***	-.62***	.92***	-

*p < .05, **p < .01, ***p < .001

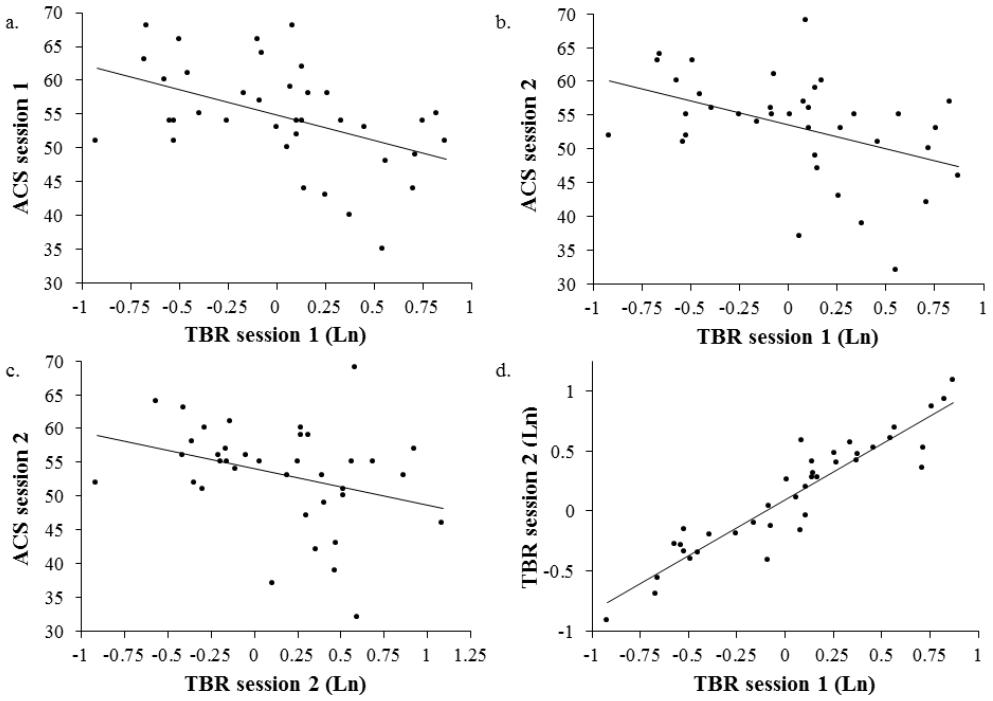

Figure 1. Scatterplots for the relations between first-session frontal TBR and ACS (n = 37) during the first session (panel a) and second session (b), frontal TBR and ACS during the second session (c), and the 2 sessions of frontal TBR (d; n = 38).

DISCUSSION

The main goal of this study was to replicate the previously reported cross-sectional relationship between spontaneous frontal EEG TBR and trait AC, and further to assess the one-week test-retest reliability of frontal TBR and its prediction of AC. Consistent with previous research (Putman et al., 2010b), a negative association was found between TBR and attentional control. This association was significant even when the measurements were conducted in different sessions. The one-week test-retest reliability of TBR was very high.

These findings are in line with previous studies (Putman et al., 2010b, 2014) supporting the idea that TBR might indeed reflect capacity of AC in healthy individuals. Most research in TBR focused on AD(H)D patients whose main symptoms are attributed to difficulties with PFC attentional regulation. Recently, there is increasing evidence that frontal TBR associates with executive control functions also in healthy individuals. ACS is a self-report measure, of the executive capacity to focus or switch attention, that has often been associated with cognitive regulation over automatic processing of threat-related emotional stimuli (Bishop et al., 2007; Derryberry & Reed, 2002; Putman et al., 2012; Schoorl et al., 2014) and spontaneous emotional regulation of threatening information (Morillas-Romero et al., 2015a). Accordingly, it has been found that individuals with high TBR have difficulties in inhibiting emotional stimuli (Putman et al., 2010b) or regulating their emotions (Tortella-Feliu et al., 2014). Neural models suggest that PFC-mediated AC is a key function in the processing of emotional information such as selective attention or cognitive reappraisal (Ochsner et al., 2012), processes that are disrupted in different types of psychopathology (Etkin & Wager, 2007; Joormann & Gotlib, 2010) so TBR's ability to predict AC is a potentially very useful biomarker.

Test-retest reliability of TBR was very high despite the fact that TBR was increased during the second session. Although other EEG spectral power densities are found to be consistent over time during resting-state (e.g., Corsi-Cabrera et al., 2007), this is the first study to our knowledge investigating the test-retest reliability of spontaneous TBR. The unexpected increase of TBR during the second session (likely due to the increased theta power), might be attributed to participants' habituation (and their possibly more relaxed state; Lagopoulos et al., 2009) as the procedure and the context were identical to the first session. Regardless, test-retest reliability of TBR and its prediction of ACS were very good and all in all, TBR seems to provide a reliable and trait-like marker of AC.

There was presently no evidence of an association between TBR and trait anxiety, which has been reported before (Putman et al., 2010b). Further research should investigate the relation of spontaneous TBR with anxiety. In summary,

these findings support the notion that frontal EEG TBR might be a stable and valuable biomarker for trait-like PFC-mediated executive control.