Neuropsychological Trends

28
November 2020

The relationship between fearful facial expressions valences and resting-state SW/FW ratio

Seyed Mohammad Mahdi Moshirian Farahi [1] **- Seyedeh Maryam Moshirian Farahi** [2] **- Mohammad Javad Asghari Ebrahimabad** [3] **- Sayyed Mohsen Fatemi** [3,4] **- Shamim Razaghi Kashani** [5]

[1] *Department of Psychology, Carleton University, 1125 Colonel By Drive, Ottawa, ON, Canada*

[2] *Department of Psychology, Salman Institute of Higher Education, Mashhad, Iran*

[3] *Department of Psychology, Ferdowsi University of Mashhad, Mashhad, Iran*

[4] *Department of Psychology, Graduate Program in Psychology, York University, Toronto, ON, Canada*

[5] *School of Social Work, University of Ottawa, Ottawa, ON, Canada*

doi : http://dx.doi.org/10.7358/neur-2020-028-mosh mjasghari@um.ac.ir

---

Abstract

Fearful facial expressions are considered dangerous and may lead to potential punishment and may be associated with behavioral inhibitions. In the present study, we examined the possible associations between the resting-state slow-wave and fast-wave ratio (SW/FW) and the valence of fearful faces. Previous studies have shown the role of SW/FW in approach-driven motivation and reward-seeking behavior. The resting-state EEG of 75 high school and undergraduate students were recorded while they were performing the valence judgment task. The results indicated a positive correlation between the global score of SW/FW and the valence of fearful faces. Moreover, multiple regression analyses indicated SW/FW in the left medial frontal as the best predictor of the valence of fearful faces. The present study confirms the previous findings underlying SW/FW mechanisms in the motivational system, including a prediction of increased SW/FW in elevated reward sensitivity and decreased SW/FW in elevated punishment sensitivity.

Keywords: slow-wave; fast-wave; SW/FW ratio; theta-beta ratio; fearful face

---

1. Introduction

The first person that scientifically studied facial expressions of emotion was Charles Darwin (Darwin, 1872). Darwin indicated that emotional expressions are presented in different types including vocal expressions, postures, and facial expressions. For instance, a fearful expression may include open eyes and mouth and may convey a shock in response to a threatening event (Zhao et al., 2017). After Darwin's theory, researchers have conducted research on emotions in order to recognize what basic emotions are. For example, Paul Ekman (1993) studied the link between basic emotions (happiness, sadness, fear, disgust, anger, surprise, and contempt) and specific facial expressions. Emotions and moods contribute to a human's decision-making process, which can result in either positive or negative consequences for subsequent behaviors. For example, fear involves low certainty and a low sense of control that would most likely increase the perception of negative events (Lerner et al., 2015). In social interactions, individuals use the facial expressions of others as important cues that can help them regulate their behaviors, understand the emotions of others and express their emotional states (Niedenthal et al., 2000).

Fear is an emotion that occurs due to the perceived risk of a threat, which causes a change in the metabolic function and eventually brings changes into one's behavior including escape or hiding (Öhman & Mineka, 2001). Fearful facial expressions may be considered as signs of danger and potential punishment and they may be associated with behavioral inhibition (Adams et al., 2006). Fearful facial expressions are also used to measure the links between attentional biases of the threat-processing system and anxiety disorder (Mogg et al., 2007). Emotional expressions are considered as two independent-dimensions, namely valence, and arousal. The arousal refers to the association between emotion and the sensation of energy and valence refers to positive/negative or approach/withdrawal tendency to emotional states (Barrett et al., 2007). In this study, we planned to measure the valence-judgment of facial fearful expressions to examine the neural mechanisms of approach/withdrawal or motivational system. Neurologically, the negative valence of fear is associated with the amygdala (Whalen et al., 2001), and negative valence of emotions is associated with prefrontal cortex, brainstem, and amygdala. This may also indicate possible roles of executive functions in the negative valence of emotions (Gerber et al., 2008). This may increase the underlying possible mechanisms of the related-biomarkers in cognitive-emotional processing that might be linked to cognitive control.

In the present study, we aimed to examine the potential cortical activity correlates of the fearful facial expressions using electroencephalography (EEG). The spectral analysis of the resting-state/spontaneous slow-wave and fast -wave ratio (SW/FW) of EEG has frequently been applied to explore approach-driven motivation and reward-seeking behavior (Knyazev, 2007). SW/FW is a valuable biomarker to measure individual differences such as emotional and cognitive processing (Knyazev, 2007; Putman et al., 2010; Cheemalapati et al., 2013; Tortella-Feliu et al., 2014). The most important application of this biomarker is to measure attentional control, or AC (Angelidis et al., 2016). It is usually measured by dividing theta band, 4-8 Hz, on beta band, 13-30 Hz (Putman et al., 2010). Theta band is most well-known in the hippocampus but has also been recorded in other cortical and limbic structures (Kocsis et al., 2001). It is also considered as a prominent signal in the nervous system related to cognitive and emotional processing and cortico–hippocampal–limbic interaction (Aftanas, et al., 2003). Studies have reported that theta activity is related to affect and psychopathology (Mulert et al., 2007; Christie & Tata, 2009). On the other hand, beta activity is associated with cognitive control and regulation of anxiety (Angelidis et al., 2018).

Fearful facial expression is directly related to anxiety (Fox et al., 2005) and is associated with behavioral inhibition system (Adams et al., 2006). Hence, the present study examined the correlations between fearful facial expression and SW/FW. In this study, we applied a valence judgment task to measure facial emotional processing. In this task, participants needed to rate the valence of facial expressions where a lower rate shows more negative valence of the expressions and a higher rate shows positive valence of the expressions. According to Schutter and Van Honk (2005), SW/FW is a biomarker of motivational imbalance of reward-punishment sensitivity. This may also indicate that SW/FW is associated with enhanced reward and reduced punishment sensitivity. High SW/FW reflects the frontal hypoactivity that is associated with low attentional control observed in individuals with ADHD (van Son et al., 2019). This hypoactivity of the frontal cortex may reflect reward sensitivity, while hyperactivity of the frontal cortex (low SW/FW) may be coupled with increased punishment sensitivity (Schutter & Van Honk, 2005) as observed in individuals with anxiety disorders. In the most relevant study, Putman et al. (2010) investigated the correlation between resting-state SW/FW, anxiety, trait motivation, and fear response inhibition using faces (fearful vs. happy) in 28 participants. They showed that the trait approach motivation is positively associated with SW/FW and negatively related to anxiety. They also found that increased fear inhibition correlates with decreased SW/FW. In another study, Angelidis et al. (2018) investigated the associations between spontaneous frontal EEG theta/beta ratio, trait anxiety, and threat-levels in 74 participants. To measure the variables, they applied a dot-probe task to measure the attentional bias and Spielberger's State-Trait Anxiety Inventory to measure trait anxiety. They reported a negative correlation between frontal theta/beta ratio, attentional bias to threat, and trait anxiety.

Therefore, we hypothesized that increased SW/FW may be related to the decreased negative evaluation of fearful faces where it is associated with increased reward sensitivity, and reversely, decreased SW/FW may be associated with increased negative evaluation of fearful faces where it is associated with punishment sensitivity. In the valence judgment task, the high rate on the valence shows decreased negative evaluation. Therefore, given the information elaborated, using the valence judgment task of fearful facial expressions may provide us with valuable emotional processing information regarding the evaluation of fearful faces as the threat cue to examine its associations with SW/FW in the frontal region, including left, right, and central frontal.

2. Methods

2.1 Participants

The participants included 75 high school and undergraduate students (age range = 11-26, age mean = 16.59, SD = 4.00, male = 67%). All participants were right-handed and had normal or corrected-to-normal visual acuity. Subjects were recruited from Ferdowsi University of Mashhad and a secondary school in Mashhad by advertisements and all subjects participated in the research as volunteers. All participants self-declared no previous psychological and neurological disorders. Participants could be able to withdraw from the study after 24 hours or whenever during the study.

2.2 Tools

2.2.1 Valence judgment task

The task consisted of videos of models making emotional facial expressions. Videos of facial expressions were obtained from the Amsterdam Dynamic Facial Expression Set–Bath Intensity Variations (ADFES-BIV; Wingenbach et al., 2016), which is based on the ADFES (van der Schalk et al., 2011). In this task, there are two aspects of facial expressions. First, basic emotions like anger, disgust, fear, happiness, sadness, and surprise. Second, complex emotions like contempt, embarrassment, and pride. Each of the emotions is expressed by 12 encoders; 7 males and 5 females. For each of the 120 videos from the Northern European set (12 encoders x 10 expressions), there are different stages of expression: low, high, and intermediate. There are 370 videos, which includes an additional 10 videos for practice trials. The length of each of the videos is 1040ms (i.e., 26 frames with a frame rate of 25/sec) (Wingenbach et al., 2016).

The task was presented on a computer monitor (19") in the resolution of 1024 x 768, appearing centrally in grayscale against a black background. The task was made in PsychoPy in Python software according to basic emotions (252 videos). On each trial, a fixation cross was presented in the center of the screen for 500 ms followed by the stimulus presented for 1040ms. We set ten minutes for presenting videos randomly. For answers to the dynamic faces, we designed a five-point Likert; 0 to 4 (0 and 1 refer to negative valences, 2 refers to natural valence and 3 and 4 refer to positive valances). Infinite response time was chosen to avoid limiting participants in their answer time producing trials with no response. Firstly, we requested the participants to read the instruction. The instruction included a presentation of instruction of five Likert answer sheets and how to mean of each point of Likert that shows in the monitor below the videos (7 emotions*12 encoders*3 levels). The emotions consisted of anger, disgust, fear, happiness, sadness, surprise, and natural face. Secondly, when participants were ready, they were requested to click the screen to start the task. The mouse cursor only appeared for the emotion labeling display within trials (Moshirian Farahi et al., 2019). All responses were recorded but only valence judgments for happiness and fear expressions entered the analyses (Figure 1).

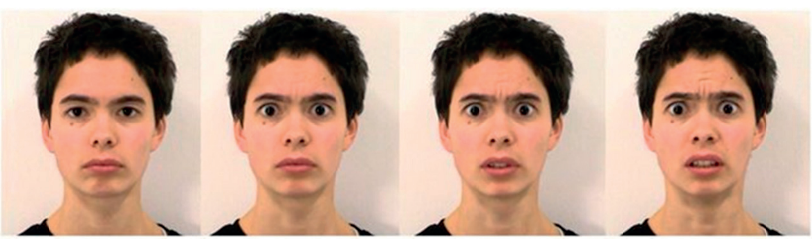

Figure 1. An example of fear expressions (left to right: the intensity of the fear expression from natural to high)

2.2.2 EEG

To record brain activity, Mitsar EEG-201 (Mitsar Co. Ltd. Saint Petersburg, Russia) was used. The device includes 19 main electrodes (Fp1, Fp2, F3, F4, F7, F8, Fz, C3, C4, Cz, P3, P4, Pz, T3, T4, T7, T8, O1, O2), two reference electrodes (A1 and A2) and a ground electrode (Fpz) according to the 10-20 system of electrode placement. The data were collected using a sampling rate of 250 Hz and filtered in WINEEG software with a frequency band of 1 to 100 Hz. Linked Ear references were used with all EEG. Electrolytic gel was applied, and each site gently abraded until impedances were below 10 kΩ. Eye-closed and eye open conditions were used for recording signals that were 3 minutes each in duration. During the eye-closed condition, we requested the participants to place their hands on the knees, half-open their mouths, and avoid blinking and opening the eyes, and during eyes open condition we requested them to additionally fixate a central point. Given the eye-closed condition, we can better infer about the resting state of the cortical activity.

After recording the signals, the data were saved as EDF+ format in WINEEG and opened in Neuroguide software. Artifact-free epochs of 250 samples were extracted through Neuroguide software and submitted to Fast Fourier Transform (FFT) and the artifacts were rejected by automatic rejection. As regards to the aims of the study, the frequency bands were theta (4–7.5 Hz) and beta activity (13–25 Hz) and we used mid-frontal theta/beta ratio. The mean of theta/beta ratio was computed in Fz, F3, F4, and total of slow and fast wave (SW/FW).

2.3 Procedure

After completing consent letters, participants completed the task and then entered into the EEG session. This study was approved by the ethics committee of the department of psychology, Ferdowsi University of Mashhad. The written consent was obtained from all participants above the age of 16 and from the parents of participants below the age of 16.

On day one, before entering the Polyclinics of Clinical Psychology (QEEG) laboratory, researchers advised participants about the experimental conditions. After that, participants entered the lab. The initial recording was done with eyes open and eyes closed in a relaxed state. On the second day, participants completed the valence judgment task. A summary of the procedure is illustrated in Figure 2.

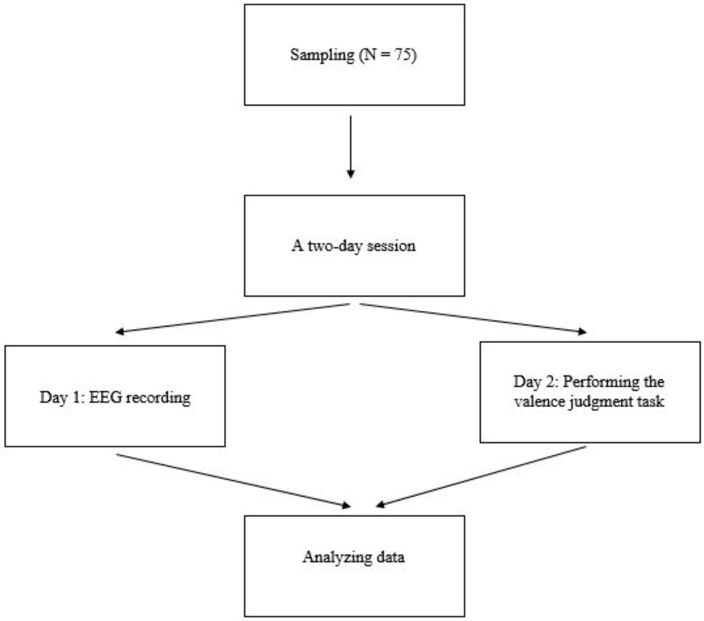

Figure 2. A summary of the research procedure

2.4 Data analysis

The data were entered into SPSS 22 (SPSS Inc., Chicago, Illinois, USA). To analyze the data, we used descriptive statistics and inferential statistics (One-way ANOVA and Multiple Regression; details in the results). First, a one-way ANOVA was conducted to compare the variables among males and females. Second, a zero-order Pearson correlation was used to show the correlation coefficients between the study's variables. Third, a multiple regression was performed in order to predict the valence of fearful faces (dependent variable) according to F3, F4, and Fz theta/beta (explanatory variables). Moreover, age was considered as a moderator variable concerning the relationships between theta/beta and the valence of fear. Also, the analysis of variances was applied to evaluate the model performance with/without the moderator variable. The criteria of the model performance were based on the MSE criterion, indicating if MSE from Model 1 to Model 2 does not noticeably change, it means the second variable cannot be retained to the model. All procedures were done after a data screening regarding multivariate normality, homogeneity of variances, and outliers. All statistical analyses were conducted considering $p < .05$.

3. Results

Considering descriptive statistic, the mean valence ratings (SD) for fearful faces and happy faces were 1.25 (.62) and 3.15 (.49), respectively. Also, the mean (SD) of theta/beta in F3, F4, F3 and total SW/FW were 2.11 (.93), 2.08 (.89), 2.28 (.99), and 2.16 (.92), respectively.

The one-way ANOVA showed no difference among male and female regarding SW/FW, $F(1, 73) = .877$, $p > .05$, F3 theta/beta, $F(1, 73) = .556$, $p > .05$, F4 theta/beta, $F(1, 73) = 1.032$, $p > .05$, Fz theta/beta, $F(1, 73) = 1.007$, $p > .05$, valence ratings for fearful faces, $F(1, 73) = .026$, $p > .05$, and valence ratings for happy faces, $F(1, 73) = .134$, $p > .05$. Table 1 shows the correlation coefficients between study's variables and Figure 3 shows the correlation between the global score of SW/FW and the valence of fearful faces with a fit line.

Table 1. Correlations between variables

	Age	Fear	Happiness	F3 theta/beta	F4 theta/beta	Fz theta/beta	SW/FW
Age	1						
Fear	-0.17	-					
Happiness	-0.14	-0.28*	-				
F3 theta/beta	-0.26*	0.30**	0.09	-			
F4 theta/beta	-0.28*	0.24*	0.18	0.93**	-		
Fz theta/beta	-0.32**	0.28*	0.19	0.94**	0.98**	-	
SW/FW	-0.29*	0.28*	0.16	0.97**	0.98**	0.99**	1

**P<0.05, **P<0.01*

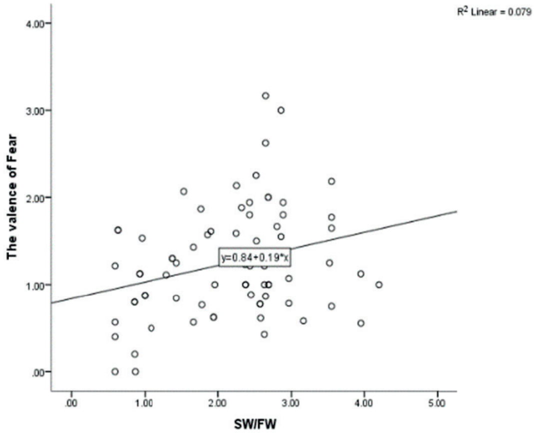

Figure 3. Scatter plot of the association between the global score of SW/FW and the valence of fearful faces

Before conducting the multiple regression analyses, we checked the multivariate normality, homogeneity of variances, and outlier assumptions. According to the residual plot against the predicted values, the normality assumption, homogeneity of variance, and outlier assumptions were met. Furthermore, the variance inflation factor (VIF) was applied to detect multicollinearity that the VIF of the models were below 2.5 (conservative level), hence, included explanatory variables were not correlated to each other.

To run the multiple regression analysis, we considered the valence of fear as the dependent variable, F3, F4, and Fz theta/beta as the explanatory variables, and age as the control variable to express the possible mediation role of age in the relationship between theta/beta and the valence of fear. Block 1 of the regression was defined by the Stepwise method to find the best set of explanatory variables and for Block 2, we put age as the control variable. The criteria to enter the variables into the model was based on $p < .05$. According to the results (Table 2), F3 theta/beta was included in the model as the best predictor of the valence of fear, indicating the valence of fear increases by .201 units of F3 theta/beta ($B = .201$, $p = .009$), see Figure 4. According to the analysis of variances, Model 1 was significant, $F\ (1, 73) = 7.253$, $p = .009$. Moreover, after controlling for age, the coefficient of F3 theta/beta decreased by .021 units, however, it remained at the significant level ($B = .184$, $p = .020$).

As we see in Table 3, MSE of Model 2 did not noticeably change after adding age to the model (Model 1 MSE = .361, Model 2 MSE = .362). Consequently, variable age cannot be considered as the second independent variable to the model, indicating variable age does not have any effect when it is added to the model, $F\,(1, 72) = .714$, $p = .401$,

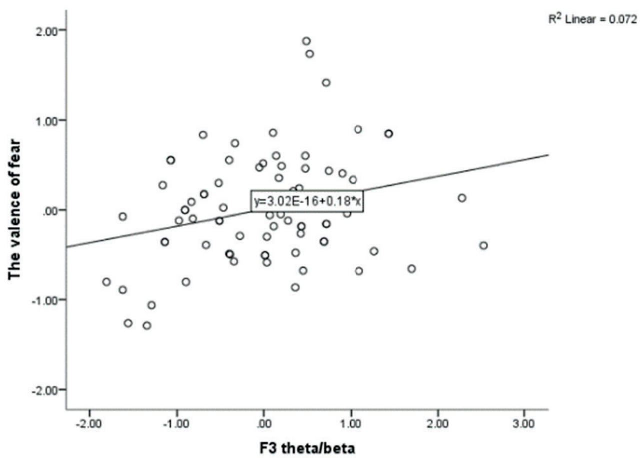

Figure 4. Scatter plot of the association between SW/FW in F3 (as the best predictor) and the valence of fearful faces

Table 2. Multiple regression

Model		Unstandardized coefficients		Standardized coefficients			95% Confidence interval	
		B	SE	Beta			Lower band	Upper band
					T	Sig		
1	Intercept	.825	.172		4.788	.0001	.482	1.169
	F3 theta/beta	.201	.075	.301	2.693	.009	.052	.350
2	Intercept	1.116	.385		2.899	.005	.349	1.883
	F3 theta/beta	.184	.078	.275	2.370	.020	.029	.338
	Age	-.015	.018	-.098	-.845	.401	-.051	.021

Table 3. Model performance

							Change statistics		
Model	R^2	Adjusted R^2	Std. error of the estimate	MSE	F	Sig	R^2	F	Sig
1	.090	.078	.600	.361	7.253	.009	.090	7.253	.009
2	.099	.074	.602	.362	3.970	.023	.009	.714	.401

Model 1: F3 theta/beta
Model 2: F3 theta/beta, age

4. Discussion

The purpose of this study was to examine the links between SW/FW and the valence of fearful faces. The results confirmed a positive association between SW/FW and the valence of fearful faces. The results of this study are consistent with Putman and colleagues (2010) and Schutter and Van Honk's (2005) studies. The findings show when SW/FW increases, the positive evaluation of the valence of fearful faces is enhanced. It reflects decreased negative evaluation on fearful faces that may be linked to increased reward sensitivity.

Based on the findings, it seems that increased SW/FW demands hypoarousal in the frontal region, especially the left medial frontal region as the regression analysis revealed. Theoretically, reduced punishment/increased reward sensitivity expresses maladaptive avoidance for threat information (Schutter & Van Honk, 2005), this maladaptive avoidance in turn normalizes the response to the fearful conditions (Mathews et al., 1990); accordingly, the findings confirmed that probably individuals who evaluate the negative valence of fearful faces more positive, may have avoidance behaviors regarding threat cues. On the other hand, it seems that individuals who evaluate the negative valence of fearful faces more negative may have more punishment sensitivity as it is also observed in high trait anxiety (Angelidis et al., 2018). Consistently, Angelidis and colleagues (2018) showed that low theta/beta ratio in the frontal region is related to high attentional bias to high threat stimuli and high trait anxiety score. Moreover, Putman and colleagues (2010) reported a negative correlation between inhibited response to fear and SW/FW. It is interpreted more negative valence on fearful faces may maximize threat/danger perception, indicating high punishment sensitivity that may recruit more hyperarousal in the frontal region.

However, there is a difference between the present study and previous studies where former investigations have considered the global score of SW/FW (Schutter & Van Honk, 2005; Putman et al., 2010; Angelidis et al., 2016; 2018). We reported the total absolute power of SW/FW and in three (left/right/central) medial frontal regions separately. The findings indicated the best predictor of the valence of fearful faces is F3 theta/beta ratio (medial left frontal region). Interestingly, it seems that the medial left frontal region is the better classifier for the valence judgment of fearful faces. Theoretically, approach and avoidance motivations are associated with the left and right frontal activity, respectively (Heller & Nitschke, 1997; Tomarken & Keener, 1998). In other words, increased left frontal activity correlates with increased approach motivation where it is associated with reward sensitivity and positive emotions (Savine et al., 2010). We found increased SW/FW in left medial frontal is related to the less negative evaluation of fearful faces and hence, decreased SW/FW in left medial frontal is associated with more negative evaluation of fearful faces. This result leads to more implications regarding the SW/FW lateralization, may leading different cognitive-emotional responses that may have psychopathological implications.

These results indicate some mechanisms of SW/FW in relation to cognitive-emotional processing in the frontal region. First, SW/FW may play a key role in the motivational system where increased SW/FW is associated with increased reward sensitivity, and decreased SW/FW is associated with increased punishment sensitivity. Second, this biomarker needs to be optimized and balanced as it seems that significant decreasing/increasing leads to abnormal motivational sensitivity. For instance, highly hyperarousal in the frontal region according to SW/FW measure may lead to an approach to a negative outcome and it may pathologically be associated with anxiety symptoms.

Additional results of the present study showed that age is negatively related to SW/FW that is consistent with previous studies (Angelidis et al., 2018; Putman et al., 2010). It is inferred that increased age is associated with decreased SW/FW in the frontal region that may reflect increased attentional control. This increment may lead to enhanced cognitive processing (Vlahou, et al., 2014). However, the valence of fearful faces was not significantly related to age. Therefore, it remains unclear whether age can affect threat-related perception or not. This non-significant result is perhaps because of the sample size that causes to decrease statistical power, though the direction of the correlation was negative, it needs to explore in a large sample size to reach an acceptable statistical power.

Nonetheless, there were some limitations to the present study. This was a correlational study and does not provide a causal effect. Also, as we observed, F3 was the best predictor of the valence of fearful faces, as we statistically controlled shared variances between SW/FW factors (F3, F4, Fz), hence, to solve those two limitations, we recommend to measure the fearful valence-judgment while EEG recording to show the causal-effect of fearful faces on SW/FW ratio in the frontal region separately to gain a better understanding regarding the mechanisms of SW/FW. Moreover, the sample size of the present study was not a homogenous sample regarding the age, although we controlled the age factor, however, a larger sample size is recommended for future studies. Though the results have implications regarding a possible positive relationship between attentional control and age, there would be a lot of confounding variables in this relationship that future studies should control.

5. Conclusion

In conclusion, the present study verifies the previous prospectus underlying SW/FW mechanisms in the motivational system. The results revealed a positive association between SW/FW (especially in F3) and less negative valence-evaluation on fearful facial expressions that provide such important mechanisms, including a prediction of increased SW/FW in elevated reward sensitivity and decreased SW/FW in elevated punishment sensitivity. The findings provided some implications concerning the possible roles of SW/FW in anxiety symptoms.

Acknowledgment

We thank Tanja S. H. Wingenbach, Ph.D. (Mackenzie Presbyterian University, Sao Paulo, Brazil) for comments that greatly improved the manuscript.

References

Adams, R. B., Ambady, N., Macrae, C. N., & Kleck, R. E. (2006). Emotional expressions forecast approach-avoidance behavior. *Motivation and Emotion*, *30*(2), 177-186. https://doi.org/10.1007/s11031-006-9020-2

Aftanas, L. I., Pavlov, S. V., Reva, N. V., & Varlamov, A. A. (2003). Trait anxiety impact on the EEG theta band power changes during appraisal of threatening and pleasant visual stimuli. *International Journal of Psychophysiology*, *50*(3), 205-212. https://doi.org/10.1016/s0167-8760(03)00156-9

Angelidis, A., Hagenaars, M., van Son, D., van der Does, W., & Putman, P. (2018). Do not look away! Spontaneous frontal EEG theta/beta ratio as a marker for cognitive control over attention to mild and high threat. *Biological Psychology*, *135*, 8-17. https://doi.org/10.1016/j.biopsycho.2018.03.002

Angelidis, A., van der Does, W., Schakel, L., & Putman, P. (2016). Frontal EEG theta/beta ratio as an electrophysiological marker for attentional control and its test-retest reliability. *Biological Psychology*, 121, 49-52. https://doi.org/10.1016/j.biopsycho.2016.09.008

Barrett, L. F., Mesquita, B., Ochsner, K. N., & Gross, J. J. (2007). The experience of emotion. *Annual Review of Psychology, 58*, 373-403. https://doi.org/10.1146/annurev.psych.58.110405.085709

Cheemalapati, S., Gubanov, M., Del Vale, M., & Pyayt, A. (2013). A real-time classification algorithm for emotion detection using portable EEG. In *2013 IEEE 14th International Conference on Information Reuse & Integration (IRI)* (pp. 720-723). IEEE. https://doi:.org/10.1109/IRI.2013.6642541

Christie, G. J., & Tata, M. S. (2009). Right frontal cortex generates reward-related theta-band oscillatory activity. *Neuroimage*, *48*(2), 415-422. https://doi.org/ 10.1016/j.neuroimage.2009.06.076

Darwin, C. (1872). The expression of emotion in animals and man. *London, England: Murray*.

Ekman, P. (1993). Facial expression and emotion. *American Psychologist*, *48*(4), 384-392. https://doi.org/10.1037/0003-066X.48.4.384

Fox, E., Russo, R., & Georgiou, G. A. (2005). Anxiety modulates the degree of attentive resources required to process emotional faces. *Cognitive, Affective, & Behavioral Neuroscience*, *5*(4), 396-404. https://doi.org/10.3758/cabn.5.4.396

Gerber, A. J., Posner, J., Gorman, D., Colibazzi, T., Yu, S., Wang, Z., Kangarlu, A., Zhu, H., Russell, J.,& Peterson, B. S. (2008). An affective circumplex model of neural systems subserving valence, arousal, and cognitive overlay during the appraisal of emotional faces. *Neuropsychologia*, *46*(8), 2129-2139. https://doi.org/10.1016/j.neuropsychologia.2008.02.032

Heller, W., & Nitscke, J. B. (1997). Regional brain activity in emotion: A framework for understanding cognition in depresion. *Cognition & Emotion*, *11*(5-6), 637-661. https://doi.org/10.1080/026999397379845a

Knyazev, G. G. (2007). Motivation, emotion, and their inhibitory control mirrored in brain oscillations. *Neuroscience & Biobehavioral Reviews*, *31*(3), 377-395. https://doi.org/ 10.1016/j.neubiorev.2006.10.004

Kocsis, B., Prisco, G. V., & Vertes, R. P. (2001). Theta synchronization in the limbic system: the role of Gudden's tegmental nuclei. *European Journal of Neuroscience*, *13*(2), 381-388. https://doi.org/10.1111/j.1460-9568.2001.01392.x

Lerner, J. S., Li, Y., Valdesolo, P., & Kassam, K. S. (2015). Emotion and decision making. *Annual Review of Psychology*, *66*, 799-823. https://doi.org/10.1146/annurev-psych-010213-115043

Mathews, A., May, J., Mogg, K., & Eysenck, M. (1990). Attentional bias in anxiety: Selective search or defective filtering?. *Journal of Abnormal Psychology*, *99*(2), 166-173. https://doi.org/0.1037/0021-843X.99.2.166

Mogg, K., Garner, M., & Bradley, B. P. (2007). Anxiety and orienting of gaze to angry and fearful faces. *Biological Psychology*, *76*(3), 163-169. https://doi.org/10.1016/j.biopsycho.2007.07.005

Moshirian Farahi, S. M., Asgari Ebrahimabad, M. J., Gorji, A., Bigdeli, I., & Moshirian Farahi, S. M. M. (2019). Neuroticism and Frontal EEG Asymmetry Correlated With Dynamic Facial Emotional Processing in Adolescents. *Frontiers in Psychology*, *10*, 175. https://doi.org/10.3389/fpsyg.2019.00175

Mulert, C., Juckel, G., Brunnmeier, M., Karch, S., Leicht, G., Mergl, R., Moller, H., Hegerl, U., & Pogarell, O. (2007). Prediction of treatment response in major depression: integration of concepts. *Journal of Affective Disorders*, *98*(3), 215-225. https://doi.org/10.1016/j.jad.2006.07.021

Niedenthal, P. M., Halberstadt, J. B., Margolin, J., & Innes-Ker, A. H. (2000). Emotional state and the detection of change in facial expression of emotion. *European Journal of Social Psychology*, *30*(2), 211-222. https://doi.org/10.1002/(SICI)1099-0992(200003/04)30:2<211::AID-EJSP988>3.0.CO;2-3

Öhman, A., & Mineka, S. (2001). Fears, phobias, and preparedness: toward an evolved module of fear and fear learning. *Psychological review*, *108*(3), 483-522. https://doi.org/10.1037/0033-295X.108.3.483

Putman, P., van Peer, J., Maimari, I., & van der Werff, S. (2010). EEG theta/beta ratio in relation to fear-modulated response-inhibition, attentional control, and affective traits. *Biological Psychology*, *83*(2), 73-78. https://doi.org/10.1016/j.biopsycho.2009.10.008

Savine, A. C., Beck, S. M., Edwards, B. G., Chiew, K. S., & Braver, T. S. (2010). Enhancement of cognitive control by approach and avoidance motivational states. *Cognition and Emotion*, *24*(2), 338-356. https://doi.org/10.1080/02699930903381564

Schutter, D. J., & Van Honk, J. (2005). Electrophysiological ratio markers for the balance between reward and punishment. *Cognitive Brain Research*, *24*(3), 685-690. https://doi.org 10.1016/j.cogbrainres.2005.04.002

Tomarkenand, A., & Keener, A. D. (1998). Frontal brain asymmetry and depression: A self-regulatory perspective. *Cognition & Emotion*, *12*(3), 387-420. https://doi.org/10.1080/026999398379655

Tortella-Feliu, M., Morillas-Romero, A., Balle, M., Llabrés, J., Bornas, X., & Putman, P. (2014). Spontaneous EEG activity and spontaneous emotion regulation. *International Journal of Psychophysiology*, *94*(3), 365-372. https://doi.org/10.1016/j.ijpsycho.2014.09.003

van Der Schalk, J., Hawk, S. T., Fischer, A. H., & Doosje, B. (2011). Moving faces, looking places: validation of the Amsterdam Dynamic Facial Expression Set (ADFES). *Emotion*, *11*(4), 907-920. https://doi.org/10.1037/a0023853

van Son, D., de Rover, M., De Blasio, F. M., van der Does, W., Barry, R. J., & Putman, P. (2019). Electroencephalography theta/beta ratio covaries with mind wandering and functional connectivity in the executive control network. *Annals of the New York Academy of Sciences*, *1452*(1), 52-64. https://doi.org/10.1111/nyas.14180

Vlahou, E. L., Thurm, F., Kolassa, I. T., & Schlee, W. (2014). Resting-state slow wave power, healthy aging and cognitive performance. *Scientific Reports*, *4*, 5101. https://doi.org/10.1038/srep05101

Whalen, P. J., Shin, L. M., McInerney, S. C., Fischer, H., Wright, C. I., & Rauch, S. L. (2001). A functional MRI study of human amygdala responses to facial expressions of fear versus anger. *Emotion*, *1*(1), 70-83. https://doi.org/ 10.1037/1528-3542.1.1.70

Wingenbach, T. S., Ashwin, C., & Brosnan, M. (2016). Validation of the Amsterdam Dynamic Facial Expression Set–Bath Intensity Variations (ADFES-BIV): A set of videos expressing low, intermediate, and high intensity emotions. *PloS One*, *11*(1), e0147112. https://doi.org 10.1371/journal.pone.0147112

Zhao, K., Zhao, J., Zhang, M., Cui, Q., & Fu, X. (2017). Neural responses to rapid facial expressions of fear and surprise. *Frontiers in Psychology*, *8*, 761. https://doi.org/10.3389/fpsyg.2017.00761