WORKING MEMORY, IMPULSIVITY AND EMOTIONAL REGULATION CORRELATES WITH FRONTAL ASYMMETRY OF HEALTHY YOUNG SUBJECTS DURING AUDITORY SESSION

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Abstract: *Background*: Specific frequency oscillations provide idea about functioning of underlying brain regions. Brain oscillations and event based assessment of cognitive functions like working memory (WM), impulsivity (Imp) and emotional regulation (ER) were reported to influence each other in different ethnic groups. But how these traits are regulated in healthy Indian adults was not explored widely. *Aims:* We analyzed link between scalp electrical activity and different neuropsychological traits in higher education aspirants. *Method:* All the traits were self-assessed using standard questionnaires. QEEG was performed during an audio-sensory session. Tracings collected through BESS software were analyzed using SPSS. *Results:* Less impulsive individuals exhibited higher frontal theta and beta activity. Higher frontal theta activity was associated with higher ER, whereas higher theta and alpha activity showed association with WM deficit. Individuals with higher Imp and happiness exhibited higher frontal hemispheric asymmetry for theta and alpha, while those with lower asymmetry for alpha and beta activity showed higher ER. Beta asymmetry was positively related with happiness. *Conclusions:* We infer that variability in behaviour of healthy adults is influenced by differential frontal brain impulses and could be considered for providing individualized assistance to emotionally vulnerable individuals.

Key words: *EEG, working memory deficit, emotional regulation*

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1. Introduction

Neuropsychological issues are increasing alarmingly with an estimated economic loss of 1.03 trillion dollars within 2012–2030 due to poor mental health conditions

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and adjusted suicide rate is expected to be 21.1 per 100,000 populations (http://www.searo.who.int/india/topics/mental_health/about_mentalhealth/en/). While economic, social, cultural, as well as biological factors affect performance of an individual, subthreshold emotional turmoil may also stem from deficits in attention, impulse control, and emotional regulation [2]. Specific diagnostic measures, identification of causative factors, efficient management system, as well as increased awareness become crucial for handling the situation.

Brain regions like prefrontal cortex, hippocampus, amygdala, and anterior cingulate cortex regulate attention, memory, emotional response and reinforcement. These regions are enriched with dopaminergic innervations and hence, the dopaminergic system and various pathways connecting the cortex, basal ganglia, and thalamus, were considered as significant regulators of these traits as well as long-term personality outcome [17].

Measurement of scalp electrical impulses through electroencephalogram (EEG) has already become an important field in neurophysiological research in different parts of the world [5, 9, 22, 28]. In healthy Austrian individuals, attention orientation was found to be systematically related to specific oscillatory brain responses [5] while approach motivation was linked to frontal asymmetry in healthy Finnish subjects [28]. In patients with psychiatric disorders, substantial differences in oscillatory frequencies were observed [9, 22].

In India, mental health issues were addressed by a number of investigators [8, 19, 23, 29] and studies involving event based assessment of traits through EEG recording were performed in patients with various disorders [3,33,34]. Investigation on visuo-spatial working memory (WM) revealed that microstate activation in the occipital, temporal and limbic cortices are associated with performance efficacy [19], while major cognitive impairment was associated with EEG signature pattern [19, 34]. Similarity in electrical impulse pattern under different psychiatric conditions also projected EEG as an effective tool for monitoring efficacy of pharmacological intervention [3].

Perspectives of life vary to a large extent giving rise to individual variability and cognitive functions like WM, logical reasoning, emotional intelligence, inhibitory control are some of the components attributing to this variation. Practice of yoga showed significant improvement in various cognitive functions, such as performance enhancement, neural activity, attention, and executive function in Indian engineering students [20]. Playing computer game for a long time was found to hamper attention, alertness and performance of healthy male Indian students [32]. However, how the long term outcome of traits is associated with EEG patterns of healthy adults under resting condition was not much explored in the Indian population. Keeping in mind the possible effect of different attributes on sensory, motor and cognitive abilities, we investigated relation between brain electrical impulse pattern and neuropsychological traits like WM, impulsivity (Imp), emotional regulation (ER), happiness, and reinforcement system, in a group of healthy young Indian subjects. Our study revealed that behaviour of healthy adults is influenced by differential frontal brain impulses.

2. Methods and Materials

Participants Thirty two healthy volunteers, comprising of 23 females and 9 males, with an average age of 25 yrs (SD ± 5.68) participated in the study. All the participants were higher education aspirants, right-handed and without any history of recognized neurological or psychiatric disorders. Each participant was informed about the purpose of the study and requested to sign an informed written consent. Basic information regarding education, family history, socio economic status, as well as professional skills was also collected. Information's regarding their basic health, inattention or focussing problem, social interaction, uncontrolled anger, chronic depression, anxiety or any deep trauma, abuse or sudden bereavement, were also recorded. Recruitment of subjects was approved by the Institutional Human Ethics Committee (PR-004-17).

EEG recording Recording was done using a 32-electrode cap (Rapid Cap) connected to a 32-channel EEG amplifier (BESS-FW-32) sampled at 1024 Hz (0.01-512 Hz band width). The ground electrode was positioned at Fz and reference electrode at Cz. Since listening to music has a positive impact on human mind [12], a background soothing music was played during EEG recording for 5 minutes in a closed eye state.

Measurement of traits Self-rating scales were used for measuring WM deficit [35], Imp [24], happiness index (HI) [13], and ER including cognitive reappraisal and suppressed expression [10]. Reinforcement sensitivity theory (RST) questionnaire [27] was used to determine RST activation domain (RST-A), RST Inhibition domain (RST-I) and RST fear-flight-fight domain (RST-F) actions. All the above traits were quantified using values from '0' for 'never' or 'no' and '3' for 'very often' or 'a strong sense of yes'.

There are three different sub domains in the scale for measuring WM deficit [35], namely deficit in attention domain (WM-AD), deficit in storage domain (WM-SD) and deficit in executive domain (WM-ED). Ten questions are included under each subdomain of WM and estimation was performed individually for each subdomain and as a whole using a total of thirty questions (WM-Full).

There were thirty questions for assessment of Imp [24], twenty-nine questions for checking HI [13] and ten questions for assessing ER [10].

RST questionnaire [27] includes eight questions for RST-A, eleven questions for RST-I and twelve questions for RST-F; analysis was done separately for individual subdomains.

Data extraction from EEG EEG tracings were analyzed using the BESS software. In brief, values collected for the frontal electrodes (FP1, FP2, AF3, AF4, F3, F4, F7, F8, FZ, FC1,FC2, FC5 and FC6) were filtered (notch filter at 50 and 100 Hz; band pass FIR filter at 3–70 Hz with order 2) and manually screened for artefacts before subjecting to power spectral analysis (Fast Fourier transform; 1s non-overlapping epochs with hamming window; 1 Hz frequency resolution; square-root transformed to represent the magnitude in μV). For each participant, absolute magnitudes of theta (4–7 Hz), alpha (8–12 Hz) and beta (13–30 Hz) frequency bands were averaged from 200 artefacts free epochs (Mean ± 26.91). Hemispheric asymmetry was calculated by taking the difference between average power value of a left hemisphere electrode and its right counterpart. These differences were converted to effect sizes using Cohen's D (CD) before correlating them with trait scores.

Statistical analysis SPSS version 22 was used to perform statistical analysis. Cohen's D (CD) was calculated online to study the hemispheric difference (https://www.uccs.edu/~lbecker/) and correlation was analyzed between CD values of absolute band frequencies and individual trait scores. Both Pearson and Spearman Rho correlation were performed. Significant observations ($P < 0.05$) from Pearson was compared with that of Spearman and similar correlation values are presented in the tables. Pooled mean and standard deviations were calculated by conventional formulae using Excel.

3. Results

Internal consistency score, checked by calculating Cronbach's alpha score for each scale, was ≥ 0.7 for all (Tab. I).

Trait	Cronbach's Alpha	Score Mean ± SD		
		All participants	Male participants	Female participants
WM-Full	0.82	28.78 ± 10.85	26.05 ± 10.70	29.32 ± 11.05
WM-AD		32.80 ± 15.66	29.26 ± 15.43	33.33 ± 16.11
WM-SD		23.66 ± 12.59	21.85 ± 13.24	23.91 ± 12.49
WM-ED		29.89 ± 12.15	27.04 ± 8.40	30.72 ± 13.17
Imp	0.80	47.58 ± 10.29	47.04 ± 4.94	48.14 ± 11.74
ER	0.72	56.09 ± 14.51	52.04 ± 14.48	58.00 ± 14.23
HI	0.98	1.87 ± 0.30	1.77 ± 0.25	1 .90 ± 0.31
RST-A	0.70	60.96 ± 13.18	61.11 ± 11.41	60.89 ± 14.05
RST-I		53.09 ± 10.61	48.82 ± 8.50	54.82 ± 11.06
RST-F		50.49 ± 8.60	53.04 ± 8.50	49.43 ± 8.60

Tab. I *Mean scores obtained for different traits measured in study participants.*

Normality for each trait was initially checked by Kolmogorv and Shapiro Wilk tests. Partial QQ plots were generated to check the distribution pattern manually. Outliers were checked using box plots. All the traits were found to have a normal to approximately normal distribution with less than 5 % outliers on an average (Mean ± SD provided in Tab. I). Most of the participants exhibited 20–30 % deficit in traits which extended up to 60 % in some cases (Fig. 1). The sub-domains WM-AD, WM-SD and WM-ED showed 10–40 % deficit, while WM-ED exhibited even 70 % deficit in some individuals. Moderate level of Imp (around 50 %) was most common while ER and HI were more or less uniformly distributed. RST-A, RST-I, and RST-F spanned between 30–70 %, 40–50 %, and 50–60 % respectively (Fig. 1).

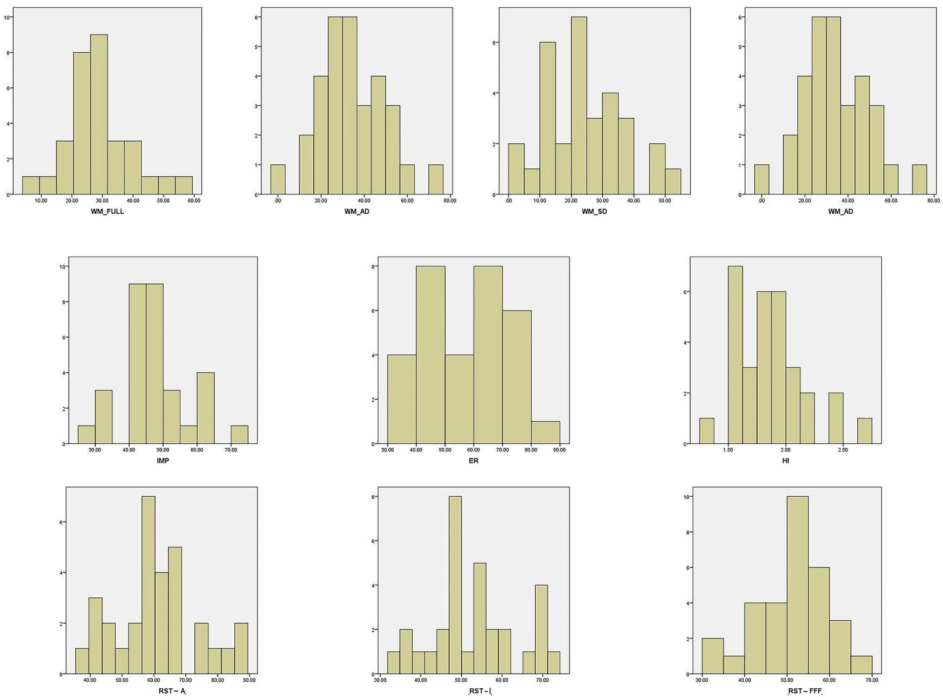

Fig. 1 *Histogram showing frequency of individuals (Y axis) with different levels of trait scores (X axis).*

Correlation between traits Full scale WM deficit and RST-I showed significant positive correlation (r = 0.45, p = 0.01). Stratified analysis showed correlation between WM-AD deficit and RST-I (r = 0.50, p =0.004) as well as WM-SD deficit and RST-I (r = 0.35, p = 0.05). HI showed negative association with RST-F (r = −0.35, p = 0.05). Stratified analysis based on gender failed to show any significant difference between the trait scores.

Correlation between magnitude of brain oscillations and measured traits A trend for positive correlation was found between average alpha and theta power in the AF3 and FZ sites with full scale WM deficit as well as WM-AD deficit (Tab. II). Average alpha power for FP2 also showed a trend for positive correlation with full scale WM deficit. Average beta powers for the frontal electrodes on the left side (F3, F7) were found to be negatively correlated with RST-I score. Alpha and theta power for the right frontal electrodes (F4, F8) showed positive correlation with full scale WM deficit and WM-ED deficit. Alpha power of fronto-central electrodes (FC1, FC6) showed significant positive correlation with WM-ED deficit and full-scale WM deficit (FC1), while beta power of the fronto-central electrodes (FC1, FC2, FC6) were negatively correlated with Imp score (Tab. II). Additionally, theta power showed significant positive correlation with ER at FC1 and WM-ED deficit at FC6, while being negatively correlated with Imp score at FC2 (Tab. II).

Electrode position	Functional trait	Frequency band	Correlation coefficient	P value
AF3	WM-AD	θ	0.303	0.09
	WM	α	0.325	0.065
FP2	WM	α	0.33	0.065
FZ	WM	θ	0.32	0.07
	WM-AD		0.332	0.065
	WM	α	0.3412	0.056
	WM-AD		0.31	0.08
F7	RST-I	β	−0.33	0.065
F3	RST-I	β	−0.31	0.08
F4	WM	α	0.31	0.08
F8	WM-ED	θ	0.33	0.065
	WM	α	0.316	0.074
FC5	IMP	β	−0.34	0.056
	WM-SD	β	−0.33	0.068
FC1	ER	θ	0.37	0.040
	WM	α	0.37	0.037
	WM-ED	α	0.47	0.007
	IMP	β	−0.35	0.049
FC2	IMP	θ	−0.45	0.009
		β	−0.44	0.011
FC6	WM-ED	θ	0.41	0.019
	WM	α	0.34	0.056
	WM-ED		0.41	0.019
	IMP	β	−0.40	0.023

Tab. II *Correlation between magnitude of brain oscillations and trait scores.*

N.B. Only absolute correlations ≥ 0.3 are shown; statistically significant correlations ($p \leq 0.05$) are highlighted in grey shading. ER: emotional regulation; IMP: impulsivity; RST-I: behavioural inhibition; WM: working memory deficit; WM-SD: WM storage domain deficit; WM-ED: WM executive domain deficit.

Correlation between hemispheric asymmetry of brain oscillations and measured traits Pooled mean and standard deviation were calculated for each electrode placed on the left and right sides of the scalp. No noticeable difference in the pooled mean score for the electrode pairs was found (Tab. III).

CD value, as a measure of hemispheric asymmetry, was then calculated for each pair of electrode and was subjected to correlation analysis with individual trait scores (Tab. IV). CD for theta (Tab. IV) showed positive correlation with Imp (F3–

Frequency band	Electrode (Left hemisphere)	Amplitude (μV) [Mean $\pm$ SD]	Electrode (Right hemisphere)	Amplitude (μV) [Mean $\pm$ SD]
θ		2.70 ± 1.64		2.41 ± 1.97
α	FP1	5.06 ± 5.62	FP2	5.13 ± 5.71
β		4.83 ± 1.47		4.84 ± 1.66
θ		2.43 ± 1.82		2.09 ± 1.04
α	AF3	4.52 ± 4.67	AF4	4.16 ± 4.10
β		4.77 ± 2.70		3.96 ± 1.06
θ		1.85 ± 1.06		1.92 ± 0.81
α	F3	3.53 ± 2.94	F4	3.62 ± 3.15
β		3.81 ± 1.11		3.72 ± 0.91
θ		2.74 ± 1.88		2.47 ± 1.42
α	F7	4.86 ± 279	F8	4.62 ± 3.80
β		5.19 ± 1.60		4.88 ± 2.18
θ		1.55 ± 1.19		1.47 ± 1.23
α	FC1	2.57 ± 1.75	FC2	2.31 ± 1.82
β		3.45 ± 2.01		3.71 ± 1.56
θ		2.12 ± 1.17		1.66 ± 1.70
α	FC5	3.42 ± 1.98	FC6	2.93 ± 2.61
β		4.35 ± 2.23		3.75 ± 0.83

Tab. III *Magnitude of brain oscillations for each inter-hemispheric electrode pairs.*

F4) and HI (F3–F4). CD for alpha was positively correlated with Imp (F3–F4 and FC1–FC2) and HI (F3–F4), while negatively correlated with ER (F7–F8). On the other hand, CD for beta was positively correlated with HI (F3–F4) and negatively correlated with ER (F7–F8). Imp score was positively correlated with theta and alpha power for F3–F4 while beta power showed a trend of negative correlation (Tab. IV). CD value obtained from average beta power of F3–F4 exhibited a trend of negative correlation with RST-A. Positive influence of FC1–FC2 alpha on Imp score was also obvious (Tab. IV), while theta showed negative influence on score for RST-F. Negative correlation between average theta and beta power of FC5–FC6 and RST-A was also noticed.

N.B. Inter-hemispheric difference in power values for each electrode pair were converted to effect sizes using Cohen's D (CD) before correlating with the trait scores. Only absolute correlations ≥ 0.3 are shown; statistically significant correlations ($p \leq 0.05$) are highlighted in grey shading. ER: emotional regulation; HI: happiness index; IMP: impulsivity; RST-A: behavioural activation; RST-F: fright-fight-flight response.

Association between gender and neural correlates Theta, alpha and beta oscillations at the fronto-polar (FP1 and FP2), anterio-frontal (AF3 and AF4), frontal (F3, F4, Fz, F7, F8) and fronto-central (FC1, FC2, FC5, FC6) electrodes showed no significant difference between male and female subjects (data not presented for brevity).

Inter-hemispheric electrode pair	Functional trait	Oscillations	Corr. coeff. for CD for the pair of electrodes	P value
F3-F4	IMP	θ	0.35	0.053
		α	0.357	0.045
		β	0.30	0.095
	RST-A	β	−0.31	0.089
	HI	θ	0.45	0.010
		α	0.48	0.005/0.006
		β	0.42	0.016
F7-F8	ER	α	−0.38	0.030
		β	−0.38	0.030
	RST-A	α	−0.35	0.054
		β	−0.35	0.055
FC1-FC2	RST-F	θ	−0.36	0.046
	IMP	α	0.40	0.020
FC5-FC6	RST-A	θ	−0.39	0.032

Tab. IV *Correlation between hemispheric asymmetry scores for brain oscillations and functional traits.*

Analysis of relative power in different regions of the brain To validate the significant correlations observed between traits and absolute wave frequencies, brain maps of relative power were compared further. At first, all the traits were classified as low and high based on the mean (± SD); scores lower than mean-SD were considered as low while scores more than mean were considered as high (Tab. I). Brain maps for relative powers were collected for all the low and high scorers for each trait and only two best representative pictures from each group are provided for WM, Imp, ER and HI (Fig. 2A–D). In each figure, the left one represents the best map from the high scoring group while the right one represents best map from the low scoring group for each trait. Subjects with relatively higher beta power exhibited low WM deficit (Fig. 2A) and low Imp (Fig. 2B), which is similar to the correlation analysis considering absolute powers. Relation between ER and inter-hemispheric difference (F7-F8) was also visible from the scalp maps; the colour pattern of high scoring individuals (Fig. 2C) was similar for alpha and beta while it was different for low scorers implying that differential activity of these brain regions may be responsible for low emotional control. Brain mapping of individuals with higher HI showed over all increased activity in the brain (Fig. 2D).

4. Discussion

Increase in professional challenges, financial constraint, anxiety, mental stress, etc. are common problems among aspirants of higher education. The condition is often neglected, eventually leading to underachievement in career. We speculated that

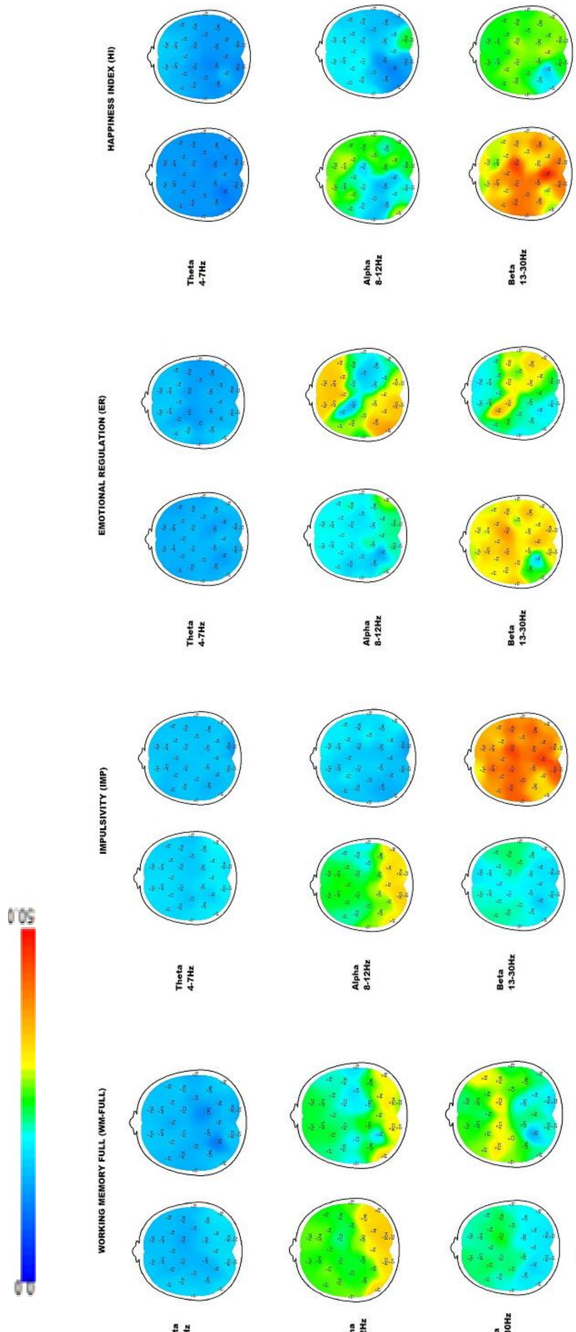

Fig. 2 *"A", "B", "C", and "D" represents brain maps of relative power for WM, IMP, ER, HI respectively. The map on the left represents the best map from high scorer while the map in the right represents the best map from low scorer. From top to bottom, brain mappings were obtained for relative power of theta, alpha and beta of each individual. The colour bar represents the strength of the signal, blue lowest (0) and red highest (50) in a gradual chromatogram.*

identification of association between brain activity and various traits may portray a different aspect altogether, providing a scope for better individualized approach to handle emotional turmoil. Based on the notion, we investigated behavioural traits of healthy adult individuals with diverse educational background. Our assessment revealed that a number of subjects suffer from low to moderate WM deficit, higher Imp, and an inefficiently balanced reinforcement system.

Brain alpha activity (7.5–12.5 Hz in adults) was earlier reported to be associated with adequate vigilance, attention, WM, perceptual abilities, information processing speed, and inhibitory processes [7, 15]. Increase in WM load, as demonstrated by greater number of retained and recalled items, was reported to be accompanied by higher amplitude of alpha oscillations [30]. However, investigators have also suggested that low frontal activity of the resting brain is related to alpha synchronisation, while event related de-synchronization of alpha oscillation reflects frontal brain activation [18, 26]. This de-synchronization presumably allows generation of beta waves associated with execution of higher order mental functions. In the current study, we have noticed higher frontal alpha and theta activity during active audio-visual session. Further analysis in association with traits revealed that this event related higher alpha and theta were correlated to higher WM deficit, especially WM-ED. We hypothesize that long term deficit in functional domains may initiate/exaggerate alpha and theta activity during an active state. Since faster brain oscillations are required for sustained cognitive activity [11, 37], it may be stated that the increased deficit could be due to higher availability of low frequency waves as well.

Impulsivity (Imp) portrays the tendency to act spontaneously in response to a stimulus and is chiefly regulated by the state of the mind, irrespective of the effect of such reactions to self and/to others [18]. Impulsive action was shown to generate from higher alertness or an over active arousal system [6] and was frequently detected in individuals with psychiatric disorders [3]. In highly impulsive individuals, impulsive conditions were differentiated by frontal asymmetry, higher resting beta power, decreased P3 amplitude, as well as decreased event-related changes in delta, theta and gamma waves [14]. Frontal beta waves also correlated with higher inhibitory control [1], indicating the efficacy of thoughtfulness in attenuating impulsive action. We have noticed a negative correlation between fronto-central beta activity and Imp; subjects with lower Imp had higher beta activity. Subjects with higher asymmetry for frontal alpha and theta activity were found to be more Imp. Additionally, our study revealed higher theta frequency at the right fronto-central location (FC2) of subjects with low Imp. In subjects with internet gambling disorder, higher Imp trait was reported to be associated with lower frontal beta activity [4]. An earlier study also documented relation between right frontal activity and enhanced inhibitory control [21].

Cognitive appraisal, a part of ER, is an important psychological trait that helps in modulating attitude thereby guiding the course of action [31]. Our study revealed positive association between ER and higher theta frequency in the FC1 region. We have also noticed higher hemispheric asymmetry for alpha and beta activity in individuals with low ER score. This is also supported by a study on healthy women showing association between compromised activity in the left prefrontal cortex and lower appraisal capability [25].

Happiness index (HI) assesses the overall state of happiness rather than momentary feeling of being happy. All the three frequency bands showed positive correlation with HI with strong hemispheric asymmetry. Therefore, HI may be influenced differentially by the two hemispheres, irrespective of the nature of activity.

Reinforce sensitivity theory (RST) illustrates the fundamental basis for individual variability. However, investigations on association between brain activity and RST revealed a mixed bag of opinion [21]. This could be due to an overlap in brain activity between various RST domains [4]. Our study failed to identify any significant relation between RST scores and the magnitude of oscillations or their hemispheric asymmetry excepting for a few trends. Among other neuropsychological traits that showed correlation with brain oscillations, we have noticed positive correlation between WM deficit and RST-I, while HI showed a strong negative correlation with RST-F. Positive correlation between WM deficit and RST-I may be explained by sharing of resources between the two, where in the increased anxiety associated with higher RST-I can cause poor reasoning ability during conflicts when WM capacity is low or WM deficit is high [16, 36]. Negative correlation between RST-F and HI is in line with a prior study that showed that unhappy individuals often show increased avoidance behaviour towards losses [38]. This overlap in behavioural expression could be due to cross talk between different RST domains and other functional traits. Accordingly, changes in brain oscillations may reflect those overlapping components that are not separated by RST domains.

5. Conclusion

The present study conducted on normal healthy Indian adults showed that basic oscillatory patterns in different brain regions may be influenced by neuropsychological attributes which could be helpful in understanding subtle changes in behaviour/emotion. Major limitation of the present study was recruitment of restricted number of subjects and types of traits assessed. However, the number of subjects recruited was sufficient to provide a correlation of 0.50 or more at 5 % significance level (80 % Power). The information generated could be helpful in building cognitive rehabilitation program for individuals suffering from prolonged functional deficiency in different neuropsychological domains. Replication of the study in large cohort would aid in understanding the challenge faced by higher education aspirants or professional achievers, thus helping the society at large.

Declarations

Ethics in publishing We hereby state that this study has been approved by the Institutional Human Ethics Committee (PR-004-17) in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki. We further state that the work described has been carried out in accordance with The Code of Ethics of the World Medical Association (Declaration of Helsinki) for experiments involving humans.

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Disclosure statement Authors declare that they have no conflict of interest.

Data availability statement Data used for the study are presented in the tables. Further information can be obtained from the corresponding author by providing reasonable justification.

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