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Infant EEG Band Power Analysis at 6 Months and 18 Months

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Abstract— **Neural development of infants has drawn increasing research interests from the community. In this paper, we investigated the frequency band power of 112 infants who participated in an auditory oddball experiment, and the visual expectation (VE) score of 177 infants who went through a visual expectation paradigm test. Analysis found that the frequency band power decreases in the delta and theta bands, and increases in the alpha and beta bands when the infants grow up from 6 months old to 18 months old. We also proposed a sustainability index to measure the capability of a subject to maintain their band power in the auditory oddball experiment when infants grow up from 6 months old to 18 months old. Analysis shows that the sustainability index increased significantly in the alpha and beta band, decreased in the delta and theta bands. Correlation between the VE score and frequency band power was investigated on 47 infants who participated in both auditory oddball experiment and visual expectation paradigm test. Analysis shows that the reaction speed to stimulus have statistical a significant correlation with the changes of band power and sustainability index in posterior and temporal section, and in the higher frequency bands.**

I. Introduction

Electroencephalography (EEG) has been used as an instrument to understand brain function, dysfunction, and cognition. Understanding of infants' neural development had drawn increasing interest. It helps in better planning of early intervention on dysfunction, such as autism [1][2][3] and cognitive ability [4][5].

Infant's brain function development had been investigated by evaluating the power spectrum of frequency bands at different sections of the brain, different stages of infancy [6]. Joni N. Saby et al. [6] reported that the peak frequencies in posterior alpha and central alpha increases about 1 Hz when infants grew up from 5-6 months to 12- 18 months. Jones et al. [4] found that theta band (3-6 Hz) of the frontal section increased significantly when infants were presented with dynamic movies of objects. It is correlated to the learning capability as the increasing of beta band power was found differently when the same dynamic movie was presented repetitively.

The reported studies focused on alpha, theta and gamma band of the EEG signal, whereas beta band received lesser attention [6]. To have a comprehensive understanding of the changes of EEG power spectrum at different stages of infancy, it is necessary to investigate the changes of frequency bands in a broader range.

Besides power spectrum of EEG, visual expectation (VE) is also used to understand neural development in infancy [7][8]. VE discovers the neural development in terms of processing speed, memory, or attention [9]. It provides a reliable approach for the assessment of infants' cognitive processes and attention [9]. VE presents visual stimuli in a fast space, Jeffry Q. et al. [7] found that the presentation of spatially patterned stimuli affects infants' reactive and anticipatory looking behavior. Research shows that infants who are quick learners might be better at extracting information about the spatiotemporal aspects of visual patterns [8].

The objective of this work is to investigate the changes of EEG power spectrum at different frequency bands when infants grow up from 6 months to 18 months old, and the correlation of such changes with VE. This study is approved by the A*STAR Institutional Review Board Ref. 2020-114. In this work, we first investigated the EEG power spectrums and sustainability of the band power over 112 infants who participated in an auditory oddball experiment when they were 6 months old and 18 months old. Then we further investigated the VE parameters of 177 infants who participated in the VE experiments when they were at 6 months old and 18 months old. We also correlated the changes of band power and sustainability level with the changes of VE scores from 47 infants who took part in both auditory oddball experiments and VE experiments.

The remaining part of this paper is organized as follows: Section II describes the EEG data set, pre-processing of the EEG signal, and VE experiment. Section III presents our findings on frequency band power. Section IV presents band power and sustainability, and correlation with VE experiments. The work is concluded in Section V.

II. EEG Data and Preprocessing

A. GUSTO Data Set

EEG data from the GUSTO project (Growing Up In Singapore Towards Healthy Outcome) [10] were used in this study. We analyzed the EEG data collected from subjects who participated in the auditory oddball tasks [10] and the VE tests [7] in GUSTO project.

The auditory oddball task consists of a stream of sounds "ma" and "na" which are common syllables of the four languages used in Singapore (English, Bahasa Melayu, Mandarin, and Tamil). Stimuli were presented in 4 blocks with a total of 1600 trials (240 "oddball" sounds), with an 800 ms

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inter-stimulus-interval (ISI), resulting in a 38 min oddball task that was immediately preceded by 3 minutes of resting. The stimulus was presented using E-prime (Psychology Software Tools). Tones were delivered at 70 dB with speakers located 55 cm equidistant from each ear. EEG data were acquired at 250 Hz.

In VE paradigm, audiovisual stimuli were first presented randomly (random phase), and then in a spatial pattern (pattern phase). Infants' eye gaze was tracked at 60 Hz using Tobii eye-tracker. Two types of looking behavior were measured: reactive looking (i.e., latency to shift eye gaze in reaction to the appearance of stimuli) and anticipatory looking (i.e., percentage of time spent looking at the location where the next stimulus is about to appear during the inter-stimulus interval). Details of the VE test are described in [7].

B. EEG signal pre-processing

Some infants fell asleep during the EEG recording period in the auditory oddball experiment. Hence, we only analyzed the initial 5 minutes of the EEG signal when the subjects were awake.

Original data were acquired with referencing channel set at Cz. Reference electrode standardization technique (REST) [11] was applied to re-reference the EEG data. EEGLAB [12] was used for EEG signal pre-processing. A 1-30 Hz band-pass filter was applied on all data set. Data were clean up before analysis. Any channel that met the following criteria was excluded from the analysis: the channel was flat continuously for more than 5 seconds, or correlation between nearby channels was less than 0.8, or line noise to signal was more than 4 in standard derivation. Data segments (0.8 s) with variance greater than 20 relative to the calibration data were excluded from the analysis.

One hundred and nineteen subjects took part in the auditory oddball experiment when they were at 6 months old and 18 months old. After data cleaning, 7 subjects were excluded from this study as the number of stimuli were less than 10. In the remaining 112 infants, 38.9% and 35.5% of data frames from the 6-month and 18-month data set were rejected during the data cleaning process.

One hundred and seventy-seven subjects took part in the VE experiment when they were at 6 months old and 18 months old. Forty-seven subjects took part in both the auditory oddball and the VE experiment when they were at 6 months old and 18 months old.

III. Band Power Analysis

Band power was evaluated using discrete FFT with a 2-second window on 5 scalp sections and 5 frequency bands. The 5 scalp sections correspond to 5 brain lobes, namely the frontal, central, posterior, left and right temporal lobes. Figure 1 shows the details of the selected channels for the 5 sections respectively. The 5 frequency bands are delta (2 -4 Hz), theta (4 – 6 Hz), low alpha (6-9 Hz), high alpha (9-13 Hz) and beta band (13 – 30 Hz) [4][13].

To investigate the band power changes of the infants when they grew up from 6 months old to 18 months old, the normalized band power of each infant at 6 months old vs. 18 months old (112 infants) are shown in Figure 2. We notice that the lower frequency band power is higher than the higher frequency band power. We computed the differences in band power when the infants were at 6 months old and 18 months old. Figure 3 shows the details of the differences in the 5 frequency bands and 5 sections, and the average of the 5 sections as well. We notice that the frequency power at the lower frequency bands (delta and theta) decreased and the higher frequency bands (low alpha, high alpha, and beta) increased as infants grew up from 6 months old to 18 months old. This observation is consistent with the observations in [6] where the researchers reported the peak frequencies moving higher in delta and alpha band when infants grew up from 5-6 months old to 12- 18 months old.

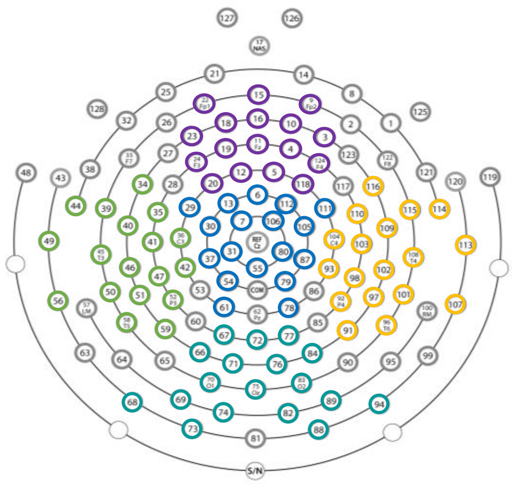


Figure 1. EEG Channel layout for the 5 sections in band power analysis.

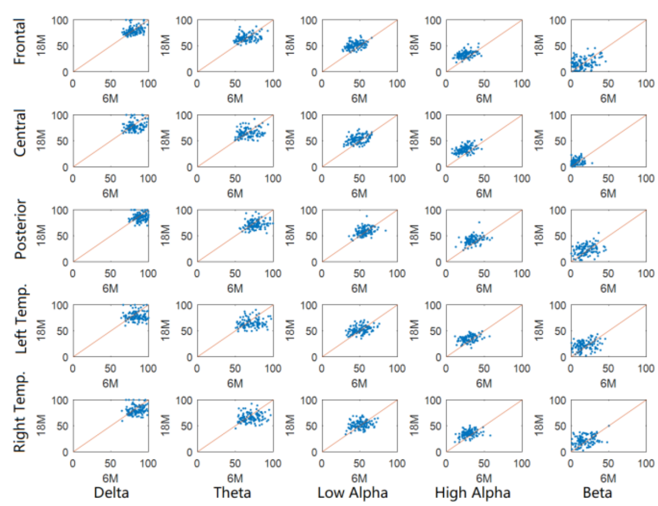


Figure 2. Normalized band power of 6-month vs. 18-month from 112 infants. The rows from top to bottom represent the frontal, central, posterior, left and right temporal lobe respectively, and the columns from left to right represent delta, theta, low alpha, high alpha, and beta band respectively.

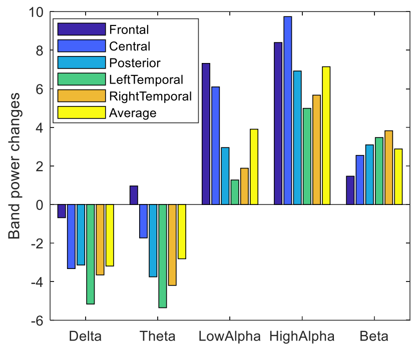


Figure 3. Band power changes between 6 months and 18 months. Band power in the delta and theta band decreases, and that of in alpha and beta band increases when infants grew up from 6 months old to 18 months old.

IV. Band Power and Sustainability, and Correlation with Visual Expectation Tests

A. Sustainability and calculation

The sustainability index is designed to quantify how well the EEG measure (power) can maintain a sufficient level. Without loss of generality, we assume that the index shall be an aggregated score that counts all the times the EEG measurement exceeds a certain threshold level – but emphasizes on time-segments of longer continuously-over-the-threshold EEG measurement. Assume a particular segment of such measurements is of length τ_i, among all $i = 1\ to\ m$ such segments. The score is defined as $\frac{\sum_{i=1}^{m} {\tau_i}^{\alpha}}{(\sum_{i=1}^{m} \tau_i)^{\alpha}}$, where α is a positive number > 1. Here we take $\alpha = 2$ in this study. To integrate the score over all permissible threshold value x, the overall sustainability index is thus defined as

$$ST = \int_x \frac{\sum_{i=1}^{m} {\tau_i}^{\alpha}}{(\sum_{i=1}^{m} \tau_i)^{\alpha}} dx \quad . \qquad (1)$$

Figure 4 shows the comparison of the sustainability index between 6-month and 18-month infants. The higher frequency bands (low alpha, high alpha, and beta) show an increase in sustainability index when the infants grew from 6 months old to 18 months old. Figure 5 shows the average increase of sustainability index at the 5 frequency bands from the 5 brain sections.

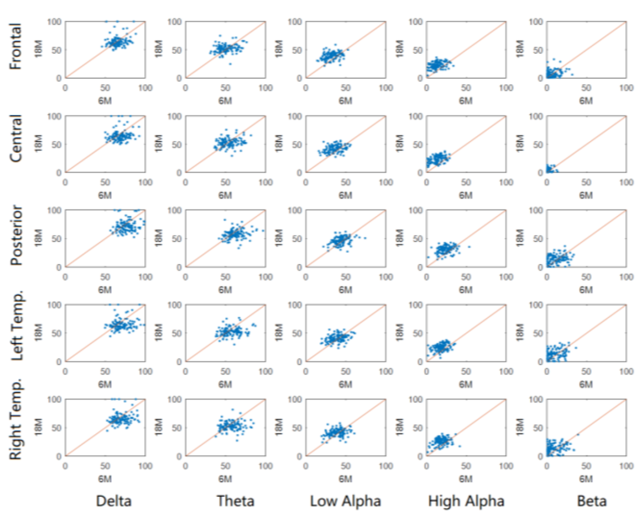


Figure 4. ST index at 6 months vs. 18 months for 112 infants, each infant is presented by a point in the subplot. The rows from top to bottom represent the frontal, central, posterior, left and right temporal lobe respectively, and the columns from left to right represent delta, theta, low alpha, high alpha, and beta band respectively.

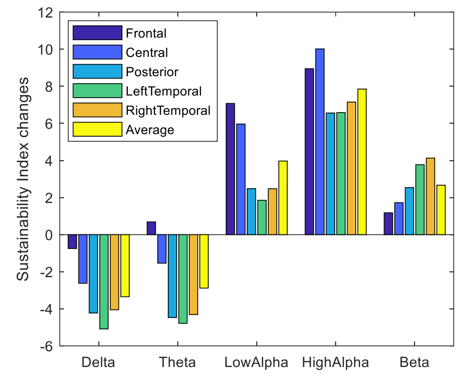


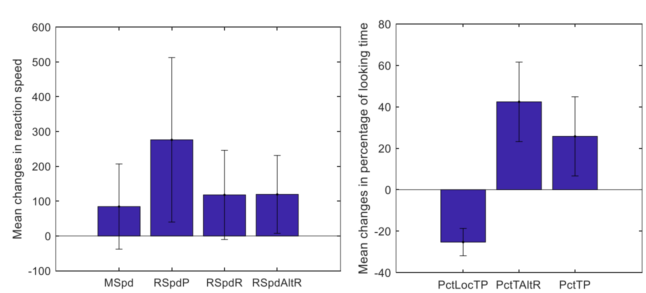
Figure 5. Changes of ST index from 6-month to 18-month. High frequency bands (low alpha, high alpha and beta) show a significant increase in ST index, whereas the lower frequency bands (delta and theta) show a decrease.

B. Visual Expectation and Correlations with EEG Band Power

Forty-seven infants had participated in both the auditory oddball and VE experiments when they were at 6 months old and 18 months old. Seven VE scores, as shown in Table 1, were extracted from the VE experiments [7] . Figure 6 shows the average changes of the VE scores from 6 months to 18 months old (47 infants). Most of the VE scores increase over the 12 months period except PctLocTP. Such positive changes are expected as the infants' cognitive capacity develops from 6 months old to 18 months old.

TABLE 1 PARAMETERS EXTRACTED FROM VE TESTS.

VE scores	Explanation
MSpd	Motor speed during random trials
RSpdp	Reaction speed to a stimulus after it appears, across all pattern trials
PctLocTP	Percentage of time spent looking at a correct location during ISI, across all pattern trials
RSpdR	Reaction speed to stimulus after it appears, across all random trials
RSpdAltR	Reaction speed to a stimulus after it appears, across alternate random trials only
PctAltR	Percentage of time spent looking at a stimulus during stimulus presentation, across alternate random trials only
PctTP	Percentage of time spent looking at stimuli during stimuli presentation, across all pattern trials



(a) (b)

Figure 6. Average changes of VE score of the infants from 6 months old to 18 months old. (a) mean changes in reaction time; (b) mean changes in the percentage of looking time. Vertical bars are standard deviations.

Correlation coefficients were evaluated between the VE scores and the normalized band power, the VE scores and the sustainability index, on their differences between the infants at 6 months old and 18 months old (47 infants). Figure 7 and Figure 8 show only the correlations with statistical significance ($p<0.05$). The changes of VE scores and that of the EEG band power and sustainability index are found negatively correlated. Out of the seven VE scores, the RSpdR and RSpdAltR are found to have statistical significant correlation with both the changes of band power and the changes of sustainability index in the posterior and temporal section, and in the higher frequency band (high alpha and beta).

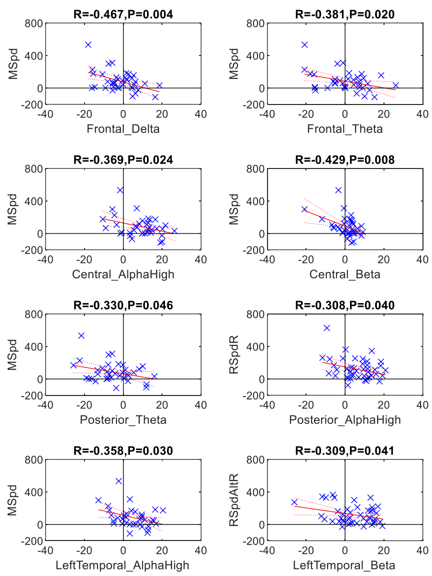


Figure 7. Correlations of the difference in band-power and the difference on VE scores (vertical axis) on infants at 6 months old and 18 months old. The horizontal axis is the difference of normalized band power at different frequency bands and brain sections.

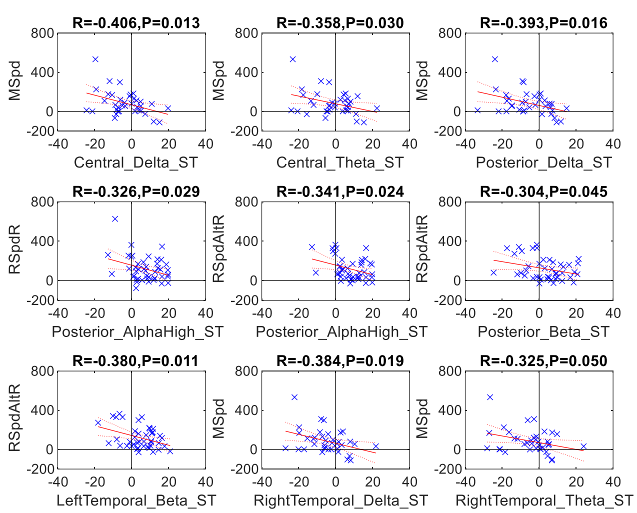


Figure 8. Correlations of the difference in sustainability and the difference in VE scores on infants at 6 months old and 18 months old. The horizontal axis is the difference of sustainability index at different frequency bands and brain sections.

V. Conclusion

We analyzed the changes of EEG frequency band power for infants at the age of 6 months old and 18 months old, and their correlation with VE scores. Our analysis shows that the lower frequency band power (<6 Hz) decreases and high frequency band power (6-30 Hz) increases as they grew from 6 months old to 18 months old. This observation is consistent with the findings by other researchers that peak frequencies in alpha band move towards higher frequency during infancy.

Sustainability Index was proposed in this work to measure the infants' capability in maintaining their band power at different ages. Analysis shows that the sustainability index increases significantly in the higher frequency band as the infants grew.

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