An EEG Coherence-Based Analysis Approach for Investigating Response Conflict Processes in 7 and 9-Year Old Children

T. Almabruk, K. Iyer, T. Tan, G. Roberts, M. Anderson

***Abstract*— Understanding the development of the brain's neural networks can reveal critical insights into the cognitive changes that occur from infancy to late childhood. Behavioural metrics including: task accuracy, stimuli recognition, and reaction time show dramatic changes over childhood. In this study we investigated response control using the Erikson Flanker task. In a dataset of 45 EEG recordings, we calculated spectral coherence to measure connectivity between all possible electrode pairs. Coherence measures were performed on two different trial conditions –congruent (where there is no response conflict) and incongruent (where response conflict is induced). The increase in incongruent coherence compared to the congruent was investigated for each electrode pair over 45 healthy subjects aged seven years. The same calculation was then performed on the same group of subjects two years later when they were aged nine years. The results revealed that at age seven years, increased coherence was detected in the left prefrontal to right and left parieto-occipital – i.e. an anatomical region located between the parietal and occipital lobes - within theta band. No increase was found for the older group-at age nine years-which may indicate cognitive development in conflict processing mechanism.**

I. Introduction

Attention is a significant component of several key mental processes (e.g., planning, working memory and inhibition) called executive functions or cognitive control [1]. These executive functions (EFs) have a vital influence in everyday life i.e., cognitive, social and psychological processes. Specifically, the term selective attention (used to assess attentional or cognitive control) which describes the attention to a particular part of a stimulus.

Research into the selective attention has revealed insights into a number of disorders such as attention deficit and obsessive compulsive disorder which were characterized by being unable to inhibit inappropriate behavioural responses [2]. From this, several psychological tasks such as Stroop task, Simon task and Flanker task were introduced in order to understand the selective attention [1].

It is proposed that for cognitive tasks involving conflict, a two-stage process takes a place to resolve the conflict [3]. In the first stage (conflict monitoring), conflict is detected and its difficulty level is evaluated. This process is associated with an activity in the anterior cingulate cortex (ACC). In the second stage (conflict resolving), conflict is resolved based on the information detected in the earlier stage. This process is associated with an activity in the lateral prefrontal cortex (PFC). The process between monitoring and resolving the conflict has been shown to be enhanced from the childhood to the early adulthood [4]. This implies that as age increases, the effect of task conflict decreases.

Rueda et al. (2004) conducted a study on four groups of children aged six-nine years to examine the development in the attentional networks (alerting, orienting and selective attention). They used an integrated version of the Attention Networks Test (ANT) developed by Fan et al (2002). This test was built on the idea of Flanker task where the target stimulus is flanked by distracting information which may or may not point to the target's direction [5]. If the flanked information point opposite to the target's direction – i.e. incongruent condition-, cognitive conflict is induced. In terms of the selective attention (selective control), conflict score was calculated as follows: 1) for each subject, a congruent median reaction time (RT) was taken over the segments of the congruent stimuli and an incongruent median reaction time (RT) was taken over the segments of the incongruent stimuli. 2) A congruent mean (RT) was performed over the congruent medians (RT) across subjects and similarly for the incongruent medians. 3) Conflict score was calculated by subtracting the congruent mean (RT) from the incongruent mean (RT). As a result of their study, conflict scores of the groups aged six-seven years were higher than that of the groups aged eight-nine years [4]. This decline in the conflict score within the old age groups was interpreted as a sign of age-related developments in the executive control network.

The anterior cingulate cortex (ACC) and the prefrontal cortex (PFC) are not the solely regions elicited by the executive functions. An integration between brain activities has been shown [6]. In this study, we measured the spectral coherence for all possible EEG electrode pairs which recorded while the Flanker task was performed. Specifically, we measured the coherence to both congruent and incongruent trials, and then took the difference between the two condition measures to reflect an individual's conflict score. To our knowledge there was no reported study assessed Flanker conflict in a longitudinal analysis of children aged seven and nine years using EEG coherence measures.

II. Materials and Methods

A. Methods

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This data set was collected by the Neurocognitive Development Unit (NDU) and approved by the ethics committee of the school of Psychology, University of Western Australia. The children's parents provided informed consent. University of Western Australia provided the EEG data sets under a formal collaboration framework with Curtin University.

B. Subjects

There were 45 healthy children aged seven years (n=45; 23 female; 22 male; mean=7.5 years; STD= 0.27). The same experiment was repeated on the same group two years later to conduct a follow-up study (n=45; 23 female; 22 male; mean=9.56 years; STD= 0.26).

C. Task Procedure

On a computer screen, subjects were faced with a child-friendly version of Flanker task and asked to focus on the central fish [7]. Five fish coloured either green or red represent the visual stimuli in three trail types:

1. Congruent, where the five green fish point in the same direction (Fig.1 (a)).
2. Incongruent, where the central green fish points in the opposite direction to the green flanking fish (Fig. 1(b)).
3. Reversed, where the five red fish point in the same direction (Fig.1 (c)).

D. Data Acquisition

An Easy-CapTM of 40 channels was used in EEG recording with electrode impedance level below 5k Ω [7]. Thereafter, a NuAmps 40-channel amplifier was applied followed by signal digitization at rate 250 Hz. Data were referenced to the linked-mastoid electrodes, and off-line filtered from 0.05 to 30 Hz using zero phase shift band-pass filter.

E. Data Analysis

The current analysis can be divided into three main steps:

1. Estimating Flanker conflict effect in the group aged 7 years based on coherence measures.
2. Estimating Flanker conflict effect in the group aged 9 years based on coherence measures.
3. Identifying age-related cognition by comparing the obtained results from step [8] and [8].

A total number of 35 EEG channels were involved in this analysis - i.e. channels Fp1, Fp2, F7, F3, FZ, F4, F8, FT9, FC5, FC1, FCZ, FC2, FC6, T7, C3, CZ, C4, T8, M1, M2, CP5, CP1, CP2, CP6, P7, P3, PZ, P4, P8, PO9, PO10, IZ, O1, and O2. Mastoid channels (M1 and M2) were excluded from the analysis after the averaged mastoid reference was applied to the data. The averaged mastoid reference was one of the reference electrodes recommended by Nunez et al. (1997) to reduce coherence measurement errors [9]. Therefore, this study was restricted to a total number of 33 channels. Although task training sessions were provided to the targeted children, they encountered a difficulty to follow up task instructions. For example, giving multiple key presses to a single stimulus and making a response either too early (< 500 ms) or too late (> 2000 ms). Such data segments were eliminated from the analysis. Thereafter, EEG data were epoched from -600 to1000 ms, and baseline corrected from -600 to 0 ms. The runica algorithm within EEGLAB toolbox was used to perform the independent component analysis ICA in order to eliminate EEG artifacts – e.g. eye blinks and muscle activity [10].


Figure 1 Flanker task conditions where the crosshair at the middle of the screen is the fixation point.

For each subject, epochs with congruent stimuli were saved in a subset differ from that of the incongruent stimuli. In the task design, 50% of the stimuli were congruent, 25% were incongruent and the other 25% were reversed (which is not of interest in the current study) [7]. Therefore, epoch counts were not equal across the conditions which may significantly affect the produced coherence measures [11]. Matching epoch counts across task conditions for each subject was recommended, and several methods were suggested. In the current study, the set of epochs with the smaller count n (most likely the incongruent set) was kept with no change and an equal count n of epochs was randomly selected from the other set (most likely the congruent set). Frequency bands were extracted by band pass filtering. Delta was defined on the range of 1-3 Hz, theta on the range of 4-7 Hz, alpha on the range of 8-12 Hz and beta on the range of 13-30 Hz. At each task condition, a 33×33 coherence matrix was calculated for each frequency band per subject. The amount of calculations in each frequency band was reduced from 1089 elements (33×33 matrix) to 528 elements (upper triangular matrix) per subject. This is because of the symmetry of coherence matrix and the unity of the diagonal elements [12]. Spectral coherence (Magnitude-Squared Coherence) c_{xy} between two signals (x and y) takes a value in the range of [0 1] and can be defined as:

$$c_{xy}(f) = \frac{|\langle s_{xy}(\mathrm{f})\rangle_n|^2}{\langle s_{xx}(\mathrm{f})\rangle_n \langle s_{yy}(\mathrm{f})\rangle_n}, \qquad (1)$$

where s_{xy} is the cross-spectrum of signals x and y. s_{xx} and s_{yy} are the auto-spectra of signals x and y respectively. Each element in the matrix represents coherence measure between two channels. The cross-spectra and auto-spectra of the two signals were averaged over non-overlapping epochs as inferred by the symbol $\langle \ldots \rangle$ in (1). With analysis frequency resolution of 1 Hz, coherence measure of the electrode pair produces multiple values associated to the number of frequencies in each band (three in delta, four in theta, five in alpha and 17 in beta). Therefore, averaging over frequencies was needed to end up with a single coherence value for each

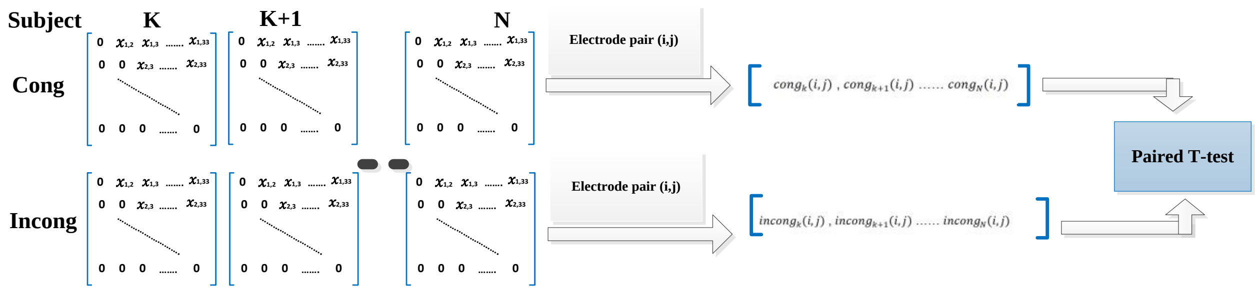

Figure 2 explains the followed procedure among the analysis to produce two data vectors for each electrode pair (i, j) to be investigated by the paired t-test.

electrode pair. Before averaging coherence measures over band frequencies, Fisher-z transform was applied to enforce the normality [13]. Therefore, parametric statistics can be applied. Two data vectors were produced for each electrode pair $(i,\ j)$ within each frequency band across subjects as explained in Fig 2. First vector contained congruent coherence measures of the electrode pair $(i,\ j)$ across subjects while second vector contained incongruent coherence measures of the same electrode pair across subjects. An important issue to mention here is to keep subjects order identical across the two data vectors. This means if the first subject has ordered as K then for example, the third element in the congruent vector and the third element in the incongruent vector were both corresponding to a subject ordered K+2. In this case, paired t-test seems to be appropriate to explore the difference between the two paired data sets. The null hypothesis H_0 of the test was that mean EEG coherence of the congruent stimuli is equal to the mean EEG coherence of the incongruent ones. The alternative hypothesis H_1 was that mean EEG coherence of the congruent stimuli is less than that of the incongruent stimuli - left-tailed test between congruent and incongruent vectors. Paired t-test was deployed with a significance level of 1%. The identified electrode pairs with the significant change at incongruent condition compared to the congruent were visualized on a topographical figure as in Fig 3.

III. Results

A. Group Aged Seven Years

The effect of Flanker conflict on the correlation between brain regions was depicted in topographical figures. This effect was investigated at each electrode pair by comparing the mean of EEG coherence measures at the incongruent condition to that at the congruent condition across the 45 subjects. In the group aged seven years as shown in Fig.3, coherence increase was detected within theta activity between left frontal polar and left parieto-occipital (FP1/PO9). Theta activity of the left frontal polar was confronted with another increase in its correlation with the right parieto-occipital (FP1/PO10). Table (1) shows the significance of coherence changes at the previous mentioned electrode pairs as investigated by the paired t-test. On the other hand, no increase in coherence measures was explored within delta, alpha and beta activities at age seven years.

B. Group Aged Nine Years

The correlations between brain regions in the old age group (nine years old) within delta, theta, alpha and beta bands confronted with no change at the incongruent condition compared to the congruent one.

IV. Discussion and Conclusions

In this paper, the positive changes in coherence values occurred regarding Flanker conflict were derived from all possible EEG electrode pairs and assessed across 45 children during two different periods of time (at age seven and nine years). In each age group, the measured synchronization of brain regions in the absence of Flanker conflict (congruent) was used as data reference to the other measurement which involved the conflict (incongruent). In order to explore coherence increase in each electrode pair across the group, the measured coherence values were paired as congruent and incongruent coherence values per subject and frequency band and thereafter tested by the paired t-test with a significance level of 1%. When significant coherence increase was detected in a particular electrode pair across the subjects, a connection links the same electrode pair was depicted on the corresponding topographical figure. In the group aged seven years, no significant difference was detected between brain synchronization networks across Flanker conditions within delta, alpha and beta activities. Instead, coherence increase was noticed within theta activity in the correlation that maps the left prefrontal area to the right and left parieto-occipital areas. The occurred increment in the left hemisphere seems to be similar to what was

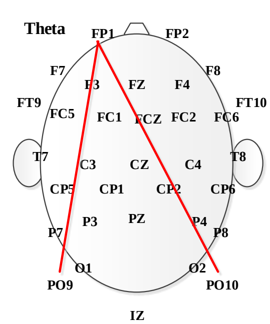

Figure 3 Topography figure of coherence differences (incongruent versus congruent) in the group aged 7 years within theta band.

reported by Thatcher et al. (1987). They found that, coherence measures of children aged four to six years compared with the younger groups were confronted with increase in the left frontal-occipital coupling [14]. They justified this by the thought that left hemisphere preceded the right hemisphere in the cognitive developments. This increase in coherence measures within theta activity seems to be disappeared two years later (at age nine years). This means that the conflict induced by the incongruent stimuli may have no effect on the older group (nine years old). This reduction in the conflict effect is consistent with Rueda et al. (2004) findings which stated that conflict score in children aged six-seven years is higher than that in children aged eight-10 years.

Table 1 shows the paired t-test statistics corresponding to electrode pairs of interest (FP1/PO9 and FP1/PO10) investigated within theta at age 7 and 9 years old.

	Age group	tstat	df	sd	P value
FP1/PO9	7 years	-2.4804	43	0.4148	0.0086
	9 years	0.1084	43	0.4816	0.5429
FP1/PO10	7 years	-2.5480	43	0.4328	0.0072
	9 years	0.2958	43	0.6187	0.6156

ACKNOWLEDGMENT

The authors would like to thank Professor Mike Anderson, School of Psychology and Exercise Science, Murdoch University, Dr Allison Fox, School of Psychology, University of Western Australia and Professor Corinne Reid, School of Psychology and Exercise Science, Murdoch University for the use of the EEG data.

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