Cortical Information Pathway of Below-Average and Average Young Hand-Writers: A Pilot Study

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***Abstract*—A great deal of study has been performed to figure out the reasons of poor handwriting. Cortical information pathway is one of the intrinsic factors that is worth considering in understanding this difficulty yet received less attention from researchers. Thus, this study was conducted to evaluate the differences in cortical information pathway between the average and below-average young hand-writers. Six pre-school children who were categorized by Handwriting Proficiency Screening Questionnaire (HPSQ) and Screen Writer as average hand-writers and four other children as below-average hand-writers were asked to trace three basic geometric shapes. Their brain signals while tracing the shapes were acquired using electroencephalograph. The information pathway was extracted from the electroencephalogram and analyzed using Partial Directed Coherence (PDC) method. The results showed that most of the below-average young hand-writers had to plan their hand movement before tracing the shapes. On the other hand, average hand-writers just only needed to recall their related experience to trace the basic shapes. In conclusion, the differences observed in cortical information pathway between the below-average writers and the average writers are essential. This finding has opened up a new research area for understanding the difficulty experienced by the below-average hand-writers and planning appropriate intervention programs to match the children's need.**

***Index Terms*—Cortical Information Pathway; Electroencephalogram; Partial Directed Coherence; Poor Handwriting**

I. INTRODUCTION

Dysgraphia or commonly called handwriting difficulty is described as a disturbance or complexity in the production of written language related to the mechanics of handwriting [1]. It is widely recognized that 10% to 33% of primary school children experience handwriting difficulty [2] which require them to spend more time to complete handwriting assignments in class. Besides, it is also noticed that their writing outputs are not neat and sometimes are unreadable and thus produced many errors such as malformed letters, overwriting, and uneven spacing [3] in their assignments or tests. These will eventually influence their academic achievements in school [4-7]. In fact, observations made by clinicians discovered that poor hand-writers are likely to protest about hand pain as well as reluctant to write and do their homework [8]. As a result, these children tend to have low self-confidence due to their underachievement in school [9]. Nevertheless, a number of children who used to be poor writers had succeeded in secondary school and at work after went through a proper intervention [10]. Hence, it is important to understand the causes of poor handwriting at the child's early-aged so that an appropriate intervention program can be designed to match his/her needs.

II. FACTORS AFFECTING HANDWRITING PERFORMANCE

Poor handwriting skill may be manipulated by two factors, extrinsic and intrinsic [11-12]. In general, extrinsic factors are referring to the surrounding or biomechanical factors that influence the handwriting such as writing materials, handwriting workload and writing instruction [13]. Some findings highlighted that the absence or presence of lines would somehow affect the handwriting quality of young children [14]. Lined paper is useful for some children as direction indicators, height borderlines, and letter positioning assistance while writing [15]. However, several researchers believed that unlined pages are able to inspire the child to write freely which leads them to use more arm muscles instead of just the fingers [16]. This in turn may reduce muscle fatigue and hand pain.

Corresponding to these factors, researchers had come out with numbers of methods to examine handwriting skills; one of it is called product legibility outcomes where evaluations are made based on the end product of different movement of writing. This method is utilized to judge the writing skills in the primary levels, which an expert is required to assess the quality of the student's handwriting [17]. However, these approaches tend to be less precise as the assessment of poor hand-writers were not standardized and not objective enough [18]. For that reason, most researchers switched their studies to a greater extent on the handwriting process instead of examining the handwriting product such as observing and evaluating the handwriting disturbance as well as proposing an analytical tool to identify the symptoms [19]. Yet, researchers are still unable to come to an agreement on the assessment tool for screening handwriting difficulty. This is due to the fact that writing system across the world are different and mostly depending on the culture [6].

Meanwhile, intrinsic factors relate to the child's actual handwriting capabilities such as fine motor skill, eye-hand coordination, visual perceptual skill, and visual motor integration skill [20]. Fine motor skill and visual motor integration skill are the two major elements in intrinsic factors that highly affected handwriting performance [21]. Fine motor skill is described as a skill that requires high degree of precision in hand and finger movement to produce any letter; those who have lower fine motor ability would normally have difficulty in handwriting [22]. Visual motor integration is defined as the ability to copy any geometric shape under the guidance of the eyes, which needs the young hand-writers to analyze and evaluate the spatial features of the shape, to arrange the strokes of lines, and to make proper neuromuscular adjustments for line control, line direction, speed, and pressure [23].

Basically, these two skills require certain regions of the brain to communicate with each other throughout the writing process such as picturing the letters or shapes, recalling the patterns, organizing the movements and creating the written product [6]. A case study was conducted by Hashim *et al*. [24] to look at the differences of cortico-cortical functional connections between children with good and poor handwriting. However, the study only participated by two children (a good and a poor hand-writers), which results in less conclusive outcomes.

III. Brain Functionality

Large numbers of movements to produce letters are similar to those required to form basic geometric shapes [10]. Hence, it is compulsory for the children to master basic geometric shapes before learning letter formation. To produce the shapes, certain regions of the brain need to communicate; not only to strategize the activity but also to give commands to the hand muscles [25].

The brain is made of four main components: cerebellum, limbic system, brain stem and cerebrum [26]. The cerebellum is the smallest part of the brain that responsible in performing balance of posture and coordination of movement. The limbic system is composed of four different sections; thalamus, hypothalamus, amygdala and the hippocampus. This part is frequently called the emotional brain because it takes in charge of human emotional response. Midbrain, pons and medulla are the three parts that make up the brain stem. It supervises the important tasks in the human body such as blood pressure, breathing, and heartbeat. Last but not least, the biggest portion of the brain, the cerebrum, which controls a huge number of important brain functions, including writing action and thought processing [27]. It consists of four lobes: occipital, temporal, frontal and parietal as indicated in Figure 1 [28].

Occipital lobe found at the back of cerebrum part, plays a role in processing visual information. There are two temporal lobes (one in each hemisphere) next to the ears. Its primary function is auditory processing, yet it may also be involved in emotion, pronunciation and learning new languages. The frontal lobe allows human to solve a complex task, undergo voluntary body parts movement and responsible for the personality traits. The functions of parietal lobe involve sensation, perception, as well as integrating sensory input. Some language functions may also be organized in this lobe [29]. Summary of the principal functions of these lobes based on the 10-20 system of electrode placement is listed in Table 1.

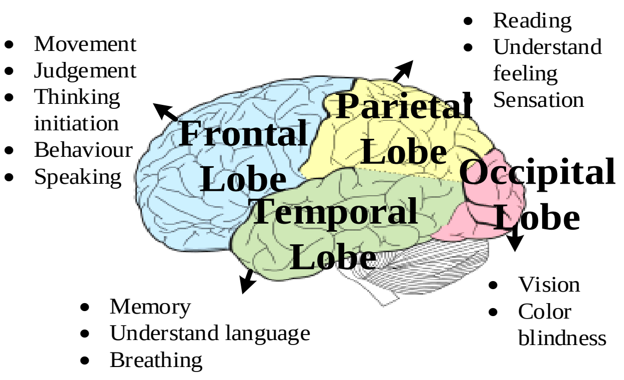

Figure 1: Cerebrum parts and functions [28]

Table 1
Principal Functions of the Ccerebrum Parts based on 10-20 Electrode Placement

10-20 Electrode Placement	Function	Principal Function
Cz	Sensorimotor integration	Sensorimotor integration both lower limbs and midline
C3		Sensorimotor integration right upper limb
C4		Sensorimotor integration left upper limb
Fp1	Attention	Logical attention
Fp2		Emotional attention (judgement)
Fz	Motor planning	Motor planning of both lower limbs and midline
F3		Motor planning right upper limb
F4		Motor planning left upper limb
F7	Expression	Verbal Expression
F8		Emotional Expression (personality behavior)
O1	Visual processing	Visual processing right half of space
O2		Visual processing left half of space
Pz	Perception	Perception (cognitive processing) midline
P3		Perception (cognitive processing) right half of space
P4		Perception (cognitive processing) left half of space
T3	Memory	Logical (verbal) memory formation and storage
T4		Emotional (non-verbal) memory formation and storage
T5	Understanding	Logical (verbal) understanding
T6		Emotional understanding

Knowing each lobe of the brain does not function alone, this work focused on examining the path of communication among the lobes while tracing basic geometric shapes. Drawing activity was chosen because it is universal and has been proven to have close functional relationship with handwriting [35-36]. Generally, a person would retrieve information from the short or long-term memory and gets them organized before start writing [30]. However, the poor young hand-writers which on occasion have trouble learning the unfamiliar written words [18] have difficulty to remember how to print or write a letter or a word. This may cause the process of organizing the stored information in memory gone off track.

In relation to the situations, it became the intention of this study to evaluate and provide general trend in cortical information pathway between the two groups of young hand-writers for better understanding their underlying strategy for writing execution.

IV. Method

A. Participants

Several pre-school children from Tadika Iman at Skudai district were randomly chosen by their teachers to participate in this study. All selected participants were six years old and right handed; right hand is the dominant hand among the hand-writers. Their handwriting proficiency was evaluated with Handwriting Proficiency Screening Questionnaire (HPSQ). HPSQ is a subjective assessment where experienced teachers were asked to complete the questionnaire based on the observations made on the children's behavior during their involvement in handwriting activities in the classroom [32]. The participants were separated into two groups (average and below-average hand-writers) based on the generated score from the questionnaire. Pupils who achieved a total score less than 14 were grouped as average writers while those who achieved a total score equal or greater than 14 were grouped as below-average writers.

In order to verify the HPSQ results, the children were re-assessed using Screen Writer, a graphic user interface (GUI) screening tool that uses children's dynamic data (while performing drawing tasks) to assess their handwriting ability [33]. Only those who fell into the same group of writers (based on the both screening tools: HPSQ and Screen Writer) were selected for the acquisition of electroencephalogram (EEG signal).

B. Instruments

Nineteen channel electrode cap (Electro-Cap Internatioanl, Inc., Eaton, OH) was applied to the subject's scalp with 2 linking on the earlobe which worked as the electrical ground. The cap was then connected to the EEG Machine (Neurofax µ EEG-9100J/K, Nihon Kohden) for brain signal acquisition. The sensitivity and frequency set for EEG Machine were 10µV and 120Hz respectively. Participants were expected to trace three basic geometric shapes as displayed in Table 2 [24]. In order to ensure the reliability of the results, each participant had been instructed to trace the required geometric shape twice.

Table 2
The three basic geometric shapes

First semicircle (S1)	Second semicircle (S2)	Triangle (Tri)
		

C. Procedures

The experiment was carried out under similar environmental conditions which each participant was placed in a special room (no noise disturbance and suitable chair and table for writing) in the pre-school. Only a researcher and one participant were allowed to be in the room in order to avoid any unnecessary disturbance. Two types of brain signals were acquired. The first signal was the control signal where the participant was in relaxed condition (free mind). This signal was used to determine if there was interference during the experiment. The second signal was the captured signal while the participant performing the tracing tasks.

All the recorded signals were compiled into Microsoft Excel in the CSV (comma delimited) format. All zeros in CSV file were deleted to minimize the EEG interferences. Partial directed coherence (PDC) method was used to the CSV format data with the help of C language to produce Tgif plotting. Tgif plot (19×19 matrices) as presented in Figure 2 was used to picture the interaction between brain regions. The PDC factor was mapped accordingly into the brain section for each source and its sink as shown in Figure 3.

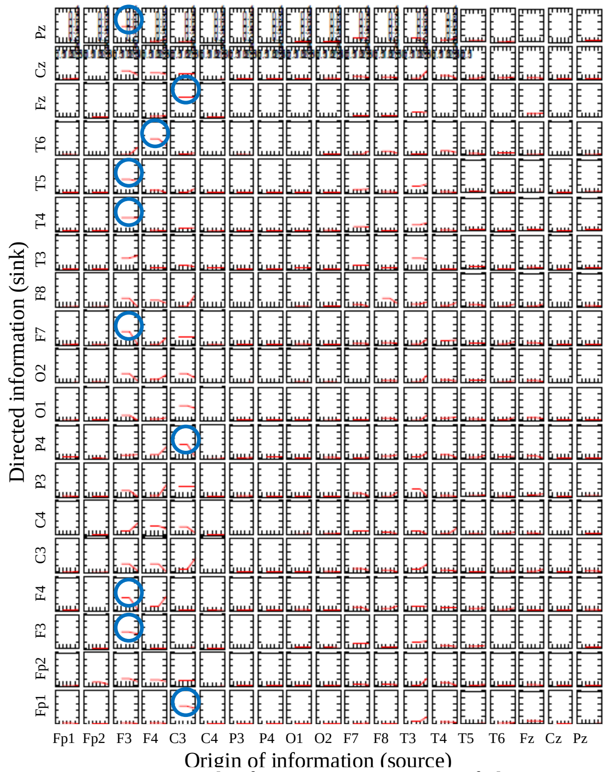

Figure 2: A sample of 19x19 matrices PDC Tgif plotting

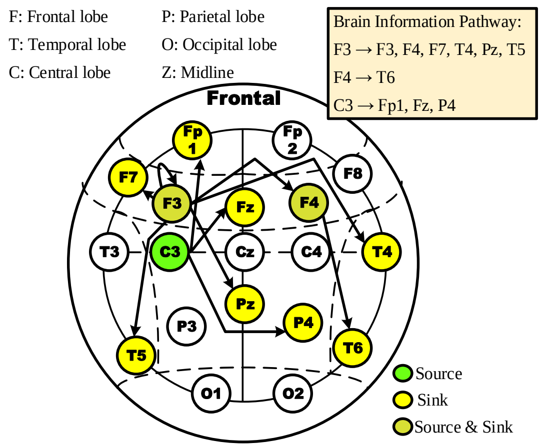

Figure 3: A sample of information pathway among the brain regions

V. Results and Discussions

By employing HPSQ and Screen Writer, the chosen young hand-writers were assured on their handwriting ability. Ten children were selected. The distribution of the participants is summarized in Table 3. It can be seen that 50% of the boys were classified as below-average hand-writers. This is parallel with the previous findings that boys are more at risk of handwriting difficulty than girls [7, 9].

Table 3
Subject Distribution

Criteria	Average Hand-writer	Below-average Hand-writer
Male	4	4
Female	2	0

Tables 4, 5 and 6 summarize all the information pathways among the brain regions while tracing semicircle 1, semicircle 2 and triangle respectively.

It can be seen from the tracing process of S1 that source of information for the below-average hand-writers came from frontal and central lobes either in the first trial or second trial. This indicates that these children need to plan their upper limb motor movement (F3 and/or F4) and use their right upper limb sensorimotor (C3) to keep track of the movement. Processes involved in this situation may include the changing of the sensory coordinates to the motor system coordinates, comparison of the required target to the current sensory state to create the motor command, and integration of the necessary commands for muscle movement [34]. As for the average writers, they may have more developed structures in brain regions that control motor performance of routine actions. Hence, they just needed to call procedural memory (verbal and emotional memories; T3 and T4) to perform the task. This is somewhat contradict to the findings reported in [24]; instead of using memory, visual processing (O1 and O2) was required by the only studied average writer.

Table 4
Brain information pathway for Semicircle 1 (S1)

Average Hand-writers			Below-Average Hand-writers		
Subject	First Trial	Second Trial	Subject	First Trial	Second Trial
1	T3→FP2 T4→T5,O2 F8→F8	T3→C3,T6 T4→F4,Fz,F7, T3,C4,P4 T5→Fp1,Fp2, F3,F8,Cz,O1	**7**	F3→F7,F4,T4, T5,O1,Pz F4→T6 C3→Fp1,Fz, P4	F3→F3,F4, Cz,P3 F4→F4,C4, Pz,P4,T5 C3→Fz,T6, F7,Fp1,O1, O2
2	T3→T3,Cz T4→Fp1,Pz F8→F8	T3→T3	**8**	Fz→Fp1,T4 T6→F3,F4,F7, T3,O1,O2	F4→F4,C4, T6,O1,O2 C3→Fp1,F7, T3
3	T3→T3,T5,P3, F3 T4→F4,T6,O2	T3→T3 T4→T4,C4, T5,Pz T5→Fp1,F7, F3,P4,T6	**9**	F3→Fz,T3,F7, F8 F4→P3,Pz,P4, T5 C3→T4,T6, O1,O2	C3→Fp1
4	T3→T3,C3, T5,Pz	T4→Cz	**10**	F3→F3 C3→Fp1	F4→F4,C4, O1,O2, T6 C3→Fp1,F7, T3
5	T4→C3	T3→F4 T4→C3,C4			
6	T4→T4	T3→T3			

The shape of S2 is just the vertically flipped of S1. Thus, it was expected from the children to use their temporary memory (T3 or T4) to complete this task. However, the below-average young hand-writers still showed the need to consciously analyze the shape and enlist strategies (activation of F3, F4, and C3) to complete S2 tracing except for one subject that was able to use his temporary memory in the second trial. Obviously, below-average writers have difficulty to remember the motor patterns of letterform [36]. Some of the below-average writers were also observed to have emotional states (Fp2 or F8) activated while completing the task.

As for the average hand-writers, they met the expectation. They had used their memory (T3 or/and T4) to complete the tracing in at least one of the trials. Involvement of logical understanding (T5) was also observed in some of the average writers. This may indicate that the participants were trying to distinguish the shape from the first activity. It is important to note that even though one of the average writers required cognitive processing (Pz) and another one required sensorimotor integration as well as motor planning in the first trial, both of them were able to recognize the shape and easily trace the shape in the second trial.

Table 5
Brain information pathway for Semicircle 2 (S2)

Average Hand-writers			Below-Average Hand-writers		
Subject	First Trial	Second Trial	Subject	First Trial	Second Trial
1	Pz→Pz	T3→F4 T4→C3,C4	**7**	F3→F3,T3,P4 F4→F7,T5,C3, P3,C4,T4 C3→Fp1,Fz,F8, P3	F3→F3,Fz,T3 F4→F4 C3→C3,O2, Fp1
2	F3→ F3,F4, F8,T6 F4→Fz,T3, P3,P4 C3→C3,T4, P4,O2	T3→T3,F3,P 3 T4→F4,C4,C 3 T5→F7,Fp1, T6	**8**	F3→ Fz,T6,Cz, Pz,C3 F4→ F7,P3,O1, C4 C3→ F7,T5,T4, P4	F3→F3
3	T4→T4, T5, C4,O2 T5→F3,P3, Fp1,Fp2	T4→T4	**9**	F3→F3,F4,Cz, O1 F4→C4,P4,F4, Pz,T5 C3→F7,Fp1,Fz, T6,O2,P3	T3→Cz,T3 T4→Fp1,Pz F8→F8
4	T3→T3 Cz→Cz	T3→Fp2	**10**	F4→P3 F3→F3,T3,Fp2 Fp2→F3,C3,T5 ,Cz,P4,C4	F3→F8,F4,T 6 F4→Fz,T3,P3 ,P4 C3→Cz,T4,P 4,O2
5	T3→C3 T4→F4,Fz, F7,P4 T5→F3, F8, Fp1,Fp2,Cz, O1	T3→T3,F3, P3,T5 T4→F4,T6, O2			
6	T5→T5,P3, F7	T5→F7			

As for the third task (tracing triangle, Tri), all average hand-writers only used their temporal lobe (T3 and T4) to trace the shape. This situation was expected since normal people would simply need to use memory to make a simple pattern. Yet, there were average hand-writers that had activated verbal understanding (T5) and emotional expression (F8) in the first trial. In the meantime, only one below-average young hand-writer traced the shape by activating his memory. Others utilized the combinations of symbol recognition (T6), motor planning (Fz, F3, F4), sensory motor integration (C3), emotional understanding (T6), and cognitive processing (Pz) to finish the task. This might be due to the shape of the triangle itself. The triangular shape has three lines; horizontal, right oblique, and left oblique. Hence, the below-average hand-writers might have to identify the shape and plan which line to draw first. However, it was noticed that three out of the four below-average hand-writers just used their memory to trace the shape in the second trial.

Table 6
Brain information pathway for Triangle (Tri)

Average Hand-writers			Below-Average Hand-writers		
Subject	First Trial	Second Trial	Subject	First Trial	Second Trial
1	T4→C3,T6	T3→T3 T4→T4	**7**	T3→Fp2	T4→T4 T5→Fp1,Fp2, C3,C4,P3,P4, T6,02
2	T3→ F4 T4→C3,C4	T3→T3,O1 T4→T4	**8**	T6→F3,F4, F7,T3,01,02 Fz→ P1,T4	T3→T3 T4→T4
3	T3→T3	T4→C4,P4	**9**	F3→F3,Fz, T3 F4→F4 C3→C3, Fp1,02	T3→Cz,P4 Pz→T3,Pz
4	T3→T3 T4→T4,C4, Pz,T5 T5→Fp1,F7, F3, P4,T6	T4→O2 T5→Fp1,F7, P3	**10**	Fz→Fz,F3, F4,C3,T3, P3,Pz Pz→F7,P3, T5 T6→T6	F3→Cz
5	T3→T4,C4 T4→Fz,Pz, T5,T6,02 F8→F3,T3, Cz,Pz, P4,F4	T3→T3,F3, P3,T5 T4→F4,T6,O2			
6	T3→Fz	T3→T3			

Figure 4 reveals the percentage of brain regions that were used by the subjects (average and below-average hand-writers) as the sources of information. Temporal region was used the most (50%). This suggests that the integration of experiences may improve the handwriting performance.

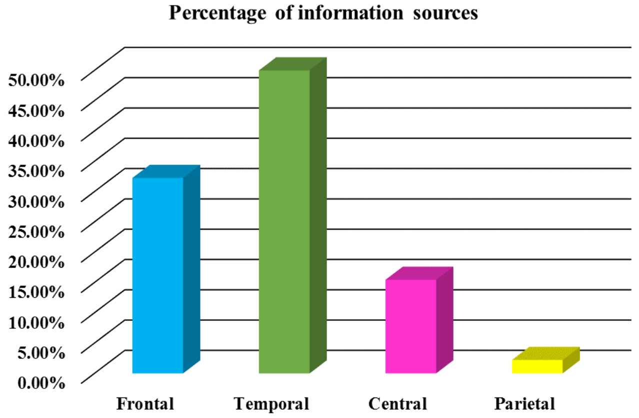

Figure 4: Percentage of information sources in the brain regions

The percentage of information sources in each region based on the task given is summarized in Figure 5. Basically, temporal and frontal regions were mainly used by the participants to draw the semicircle shapes (S1 and S2). The use of temporal region was noticed to be higher than the frontal region for S1 and vice versa for the S2. High usage of the frontal region while tracing S2 specifies the requirement of planning for the subjects to vertically flip the first shape, S1. However, 78% of the subjects used temporal region when completing the third task which shows that most of the participants in general had recognized the shape.

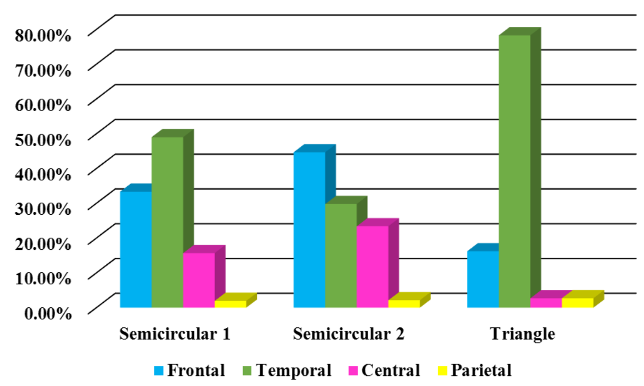

Figure 5: Percentage of information sources for each task

Overall, this study highlights that below-average hand-writers merely depend on the sensory motor (C3) and motor planning (F3 or F4). This signifies that the below-average hand-writers need to recognize the shape and plan what they want to execute even for a simple geometric shape tracing. The findings are in accordance with the findings reported in [24]. The need for the below-average writes to recognize the shapes and plan their muscles movement may become one of the reasons why below-average writers have been reported to have an overall slower writing speed than the average writers [37]. These findings may also explain why the detection of unautomated movement due to disruption or control in children's execution is used to diagnose and treat handwriting difficulty [38].

VI. Conclusion

This paper has shown the difference in the information pathway among the brain regions between the two groups of young hand-writers. In general, the below-average young hand-writers require motor planning (F3, F4) and sensorimotor integration (C3) whereas the average hand-writers just need to activate memory formation and storage (T3, T4) to trace the basic geometric shapes. These findings provide new insights into information pathways in the brain. Further research with a larger number of samples on this area may provide results that better reflect the target population and facilitate our understanding on the difficulty experienced by the below-average hand-writers.

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