Handwriting Dynamic Features and Brain Electrical Activity Related to Graphic Rule Based on Principal Component Analysis

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***Abstract*—For handwriting difficulties, many have independently studied the dynamic feature of handwriting process and brain neural activity with respect to the graphics rule. However, a very little study has been done to analysis these two factors concurrently. Thus, this study aimed to determine the most significant parameter in differentiating the preferred (good hand writer) and non-preferred (poor hand writer) based on both dynamic features of drawing process and brain electrical activity by using Principal Component Analysis (PCA). Children's Visual-Motor Integration (VMI) skills were assessed by instructing him/her to freehand copy eleven geometrical figures with different figure's complexity. The dynamic feature of handwriting process and electroencephalogram (EEG) signal were recorded concurrently during drawing tasks. A total of 233 parameters were extracted, and PCA was applied to obtain low dimensional subspace of parameters. It was found that the most significant parameter was a high gamma band of the occipital area, O_2 during tracing activity of a square shape. It is known that those employed, preferred graphics rules are good handwrites and has better academic performance. Hence, it is proposed that that employed, preferred graphics rule has better visual processing as one indicator for better academic performance. Meanwhile, the dynamic features showed less significant association with the graphics rule.**

***Index Terms*—Dynamic Features; Electroencephalogram; Graphic Rule; Principal Component Analysis.**

I. INTRODUCTION

Handwriting is an activity which involves complex skills and the learning of it usually begins around the age of three to four years old. Nowadays, living in the information age of human history, writing ability is no longer optional but has become an essential skill which should not be taken for granted by both parents and early educational institution.

It has been scientifically proven that proficiency in such skill among school children would support their cognitive development [1], influences reading [1,2], writing [2], language and critical thinking [3]. Moreover, it has been claimed that children's overall academic achievement is linked with their handwriting proficiency [4,5]. These findings provide useful insight and additional evidence which reflect the importance of writing ability among children at their early age. However, it is estimated around 25-33% of school children are having difficulties in their writing's ability [6]. Hence the study of handwriting difficulties has become a great concern as neglecting it would give adverse consequences towards respective children in term of their psychological behaviour and academic performance.

To avoid such issues, 'poor' writer needs to be identified as early as possible and needs to be referred to the occupational therapy for further intervention programs. One classical and the most consistent method exist is to observe children's Visual-Motor Integration (VMI) skill by instructing him/her to freehand copy some geometrical figures with different figure's complexity and the product of it (static data) would be directly evaluated. However, as the figure's complexity increases, the reliability of a direct human assessment is ambiguous and could be disputed. Thus the dynamic data drawing process has been extensively studying to serve as additional predictors. In recent years, many of previous researchers have studied the extraction of dynamic features concerning the use of graphics rule – consist of starting rule (where to begin) and progression rule (which direction to proceed) (Figure 1). It has been shown that the use of graphics rules is indeed related to the handwriting proficiency [7]. This works by having an assumption in which poor writer would haphazardly demonstrate graphic rule (non-preferred) while good writer would demonstrate otherwise (preferred). Figure 2 shows drawing an example for preferred (left) and non-preferred (right) subjects.

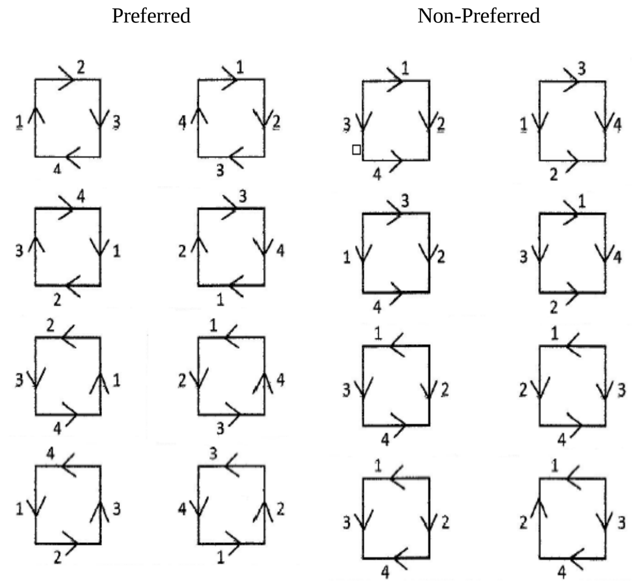


Figure 1: Example of preferred and non-preferred graphic rule pattern for the square task (1-starting direction, 2, 3 and 4-progression rule)

It has been shown that handwriting difficulties are not only restricted to the use of dynamic features and graphics rule. It was found that the strategy of graphics rule would also engage in the neural activity of a human being. As reported by [2], the brains of poor writer consumed more oxygen compared to the good one for the brain demanded more energy to complete a given task. Another related study conducted by [8] which investigates the directional connectivity in the brain during drawing tasks reported that the poor writer's brain frontal area does not have any input from any other sources while the good writer's brain frontal area was observed to receive functional information from the occipital area. These findings show handwriting proficiency does engage in the neural activity of human brain hence signify the importance of it which needs to be further explored.

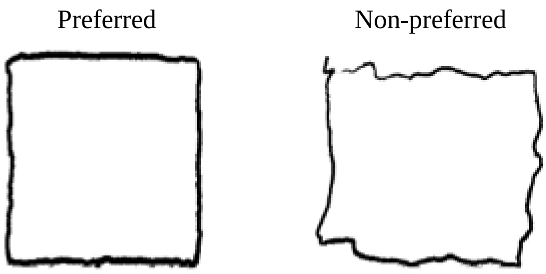


Figure 2: Example of drawing made by preferred and non-preferred subjects

To summarise, the works of dynamic feature and the brain neural activity concerning the handwriting difficulties are already being researched extensively. However, there is a limited study in which these two factors (dynamic features and neural activity) are concurrently being considered. Thus, this study aims to determine the most significant feature (parameter) in differentiating the preferred and non-preferred based on the drawing process of dynamic features and brain electrical activity by using Principal Component Analysis (PCA). Earlier work was done with only twelve subjects, and four shapes [9] and this paper extended the findings with sixty subjects and eleven geometric shapes.

II. METHODOLOGY

A. Experimental Setup

Sixty male and female children (5-7 years old) from Tadika Ihsan Universiti Teknologi Malaysia (UTM) voluntarily participated in this study. There were 20 participants per age group. A consent form was provided with sufficient information on benefits and risks associated with the study. Before the data acquisition session, subjects were given a brief explanation regarding the experimental procedure, and the international 10-20 system of EEG cap was then attached to subject's scalp. Subjects were asked to complete three consecutive sessions of experiments which were Control Task, Drawing Task (Gaze) and Drawing Task (Trace).

For the control task, the subject was required to be at rest (relax) with eyes open for ten seconds while EEG signal was being recorded. Next, for drawing task (gaze), the subject was required to attend his/her attention to a given shape which was printed on an A5 paper while EEG signal was being recorded for another ten seconds. Then, for drawing task (trace), the subject was required to trace a given shape within 10 seconds onto a WACOM tablet by using wireless electronic inking pen, and during that period both EEG signal and dynamic features of drawing process were concurrently being recorded. Eleven standard shapes of VMI were given where the subject was free to choose their own graphics rule during the tracing process, and 5 minutes rest duration was given between each respective task. All these are summarised in Table 1. Meanwhile, Figure 3 illustrates a process flow of the experiment.

Table 1
Summary of the Experimental Set-Up

Subject		60 children (male and female, 5-7 years old)
Shape		1) Horizontal line 2) Vertical line 3) Right oblique 4) Left oblique 5) Square 6) Cross 7) Oblique cross 8) Triangle 9) Right semicircle 10) Left semicircle 11) Circle
Data acquisition	Dynamic features of the drawing process	• Time • Velocity • Pressure • Altitude • Azimuth
	EEG frequency band	• Delta • Theta • Alpha • Beta • Gamma • High Gamma *for 19 electrodes position, 6 frequency bands and each drawing task (gaze) and drawing task (trace) a total of 228 parameters were extracted
Analysis		PCA

B. Principal Component Analysis (PCA)

For five (5) dynamic features of handwriting process and 228 frequency bands concerning the 19 electrodes position and two different tasks, there were all together, 233 extracted parameters (P1-P233) which were analysed. To reduce data redundancy, an analysis of unpaired t-test was conducted by only considering the most significant parameter/s concerning the control task. The selected data were then pre-programmed into R software for further analysis.

The first and second component contributed to the variance to the whole dataset which is sufficient to model the systematic variation of the dataset. Thus, it provides a meaningful visual representation of the subjects and parameters. It was assumed that the two components have a sufficient amount of the variance, allowing discovery of ~70% of the variance in the dataset. If dimension 1 (PC1) was insufficient to model the systematic variation of a dataset, the second component dimension 2 (PC2) was considered.

III. RESULT AND DISCUSSION

The performance of all subjects during the experiment is tabulated in Table 2. Good performances refer to the used of stroke patterns that follow the governed rule fashion (preferred rule) as illustrated in Figure 1. It was observed that the number of preferred subject is higher than the number of non-preferred subjects except in task 3 (right oblique) of 7 years old children (8 preferred, 12 non-preferred). In general, it was demonstrated that an increase of age does not affect the performance of subjects with the exception for task 10 (left semicircle), where the number of preferred subjects was observed to increase linearly with children's age (55% at 5 y/o, 65% at 6 y/o and 90% at 7 y/o). The results from current study highly suggest in which mature children do not necessarily display good performance in drawing task.

Meanwhile, Table 3 shows the p-value of dynamic handwriting features for all eleven tasks and subjects. There was a significant difference in pressure during task 5 (square) and 9 (right semicircle). The significant difference for both velocity and altitude was also observed during task 8 (triangle) and 10 (left semicircle), respectively. No significant difference was observed between the subject with a preferred and non-preferred rule for the rest of the tasks. The results imply that the extraction of dynamic features alone does not have much effect in differentiating the good and poor drawing performance.

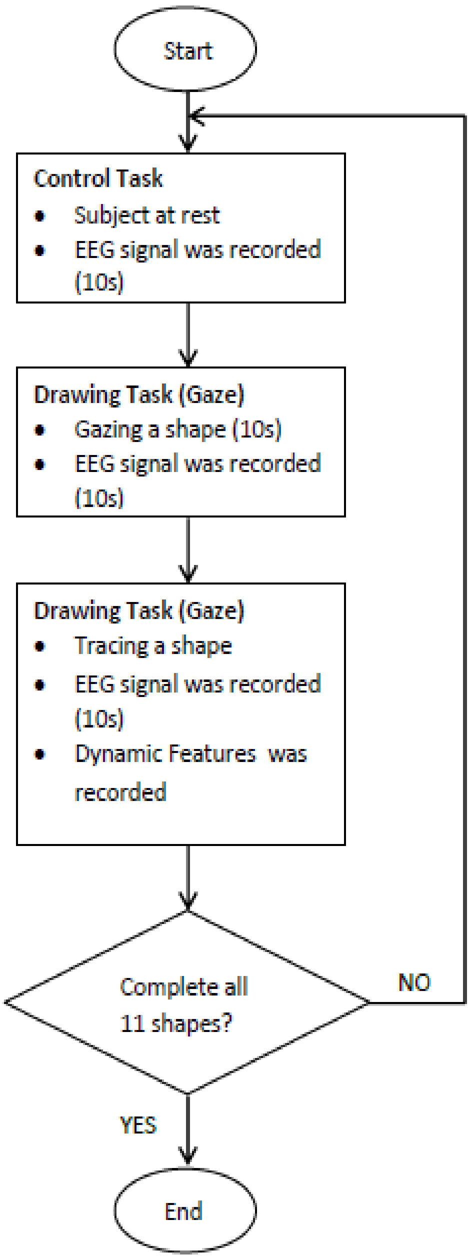


Figure 3: Experimental flow diagram

Table 2
Subjects Performance (%) for Preferred and Non-preferred Rule against Task (y/o: years old, P: Preferred, NP: Non-Preferred)

Task	5 y/o		6 y/o		7 y/o	
	P	NP	P	NP	P	NP
Horizontal line	70	30	85	15	90	10
Vertical line	75	25	90	10	90	10
Right oblique	70	30	85	15	40	60
Left oblique	75	25	80	20	80	20
Square	90	10	75	25	85	15
Cross	85	15	80	20	80	20
Oblique cross	90	10	90	10	85	15
Triangle	85	15	75	25	90	10
Right semicircle	90	10	85	15	60	40
Left semicircle	55	45	65	35	90	10
Circle	90	10	85	15	90	10

Table 3
P-value of Dynamic Feature from t-test Analysis Between Subject with Preferred and Non-Preferred Rule

Task	Time	Velocity	Pressure	Altitude	Azimuth
Horizontal line	n.s	n.s	n.s	n.s	n.s
Vertical line	n.s	n.s	n.s	n.s	n.s
Right oblique	n.s	n.s	n.s	n.s	n.s
Left oblique	n.s	n.s	n.s	n.s	n.s
Square	n.s	n.s	p*	n.s	n.s
Cross	n.s	n.s	n.s	n.s	n.s
Oblique cross	n.s	n.s	n.s	n.s	n.s
Triangle	n.s	p**	n.s	n.s	n.s
Right semicircle	n.s	n.s	p*	n.s	n.s
Left semicircle	n.s	n.s	n.s	p*	n.s
Circle	n.s	n.s	n.s	n.s	n.s

Note:
n.s : not significant
* : $p < 0.05$
** : $p < 0.01$

Figure 4 shows a linear combination of the first and second component accounted for the variances of each task. It was found that task 5 (square task) has the highest quality differences in differentiating between preferred and non-preferred for it has the highest variance (71.78%) compared to the rest. The most significant positive parameter concerning the task 5 was found to be a high gamma band of the occipital area, O_2 during tracing (P120) activity as shown in Figure 5. This might be due to the involvement of more rules to complete the drawing as the square task has four steps including starting and progression rule. It is found that the brain's location is consistent with the previous study [8] where the functional information was found to be originated at occipital area among good hand writers. It is known that those employed, preferred graphics rule are good handwrites and has better academic performance. Hence, it is proposed that those employ, preferred graphics rule has better visual processing as one indicator for better academic performance.

IV. Conclusion

To conclude, the term 'preferred', and 'non-preferred' rule concerning the differences in drawing skills not only refers to the ability of one to solve a task but also refers to an individual's way of thinking pattern and strategy to solve a task. In this study, it was found that the most significant parameter in differentiating between preferred and non-preferred was a high gamma at O_2scalp location of squaring task.

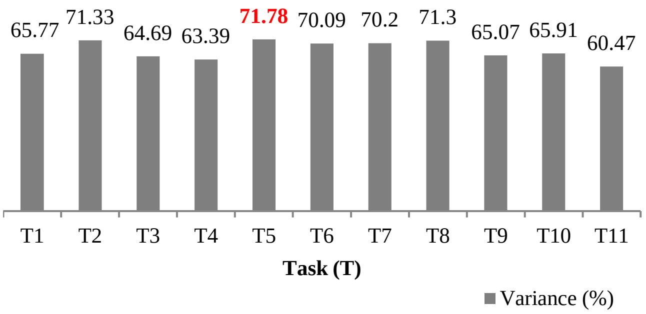
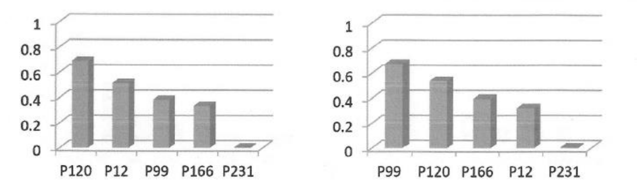


Figure 4: A linear combination of the first and second component analyses accounted for the variances of each task.



	Parameter
P120	High Gamma Trace O_2
P12	High Gamma Trace Fp_1
P99	Alpha Gaze O_1
P166	Beta Trace T_4
P231	Pressure

(a)

	Parameter
P99	Alpha Gaze O_1
P120	High Gamma Trace O_2
P166	Beta Trace T_4
P12	High Gamma Trace Fp_1
P231	Pressure

(b)

Figure 5: The score ranking graph bar of (a) PC1 and (b) PC2. The x and y-axis indicate parameter and score, respectively.

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