

**EXPLORATION OF HANDWRITTEN  
ALLOGRAPHIC FEATURES ATTRIBUTED TO  
THE PRIMARY EDUCATIONAL BACKGROUNDS  
OF MALAYSIAN WRITERS FOR FORENSIC  
COMPARISON**

**LINTHINI A/P GANNETION**

**UNIVERSITI SAINS MALAYSIA**

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by

**LINTHINI A/P GANNETION**

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for the degree of  
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## LIST OF SYMBOLS

$>$	More than
$<$	Less than
$\%$	Percentage
$P_1$	Estimated larger population
$P_2$	Estimated smaller population
$y_i$	Multicategorical nominal outcome
$i$	Total categories of outcome
$\alpha$	Intercept
$\beta_1$	Coefficient in independent variables
$\beta_2$	Coefficient of confounding variables
$X$	Variable values
$\mu$	Random effect of respondent level
$\mu_i$	Random effect of respondent level with variations
$\sigma^2$	Variations
$\chi^2$	Chi square value

## LIST OF ABBREVIATIONS

ANOSIM	Analysis of Similarities
CART	Classification and Regression Tree
CI	Confidence interval
df	Degree of freedom
FDDM	Forensic DNA Databank of Malaysia
FDE	Forensic Document Examiner
ID	Identification
k-nn	k-nearest neighbour
MAFIS	Malaysia Automates Fingerprint Identification System
MRSM	MARA Junior Science College
OR	Odds ratio
POL	Pupil's Own Language
QDE	Questioned Document Examiners
SJK(C)	Chinese National Type Schools
SJK(T)	Tamil National Type Schools
SPM	Sijil Pelajaran Malaysia
SVM	Support Vector Machines
UCL	Upper confidence limit
USM	Universiti Sains Malaysia
JKM	Department of Chemistry Malaysia
QUWI	Qatar University Writer Identification dataset

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**PENEROKAAN CIRI ALOGRAFIK TULISAN TANGAN YANG  
DIKAITKAN KEPADA LATAR BELAKANG PENDIDIKAN SEKOLAH  
RENDAH BAGI PENULIS MALAYSIA UNTUK PERBANDINGAN  
FORENSIK**

**ABSTRAK**

Ciri kelas dalam tulisan tangan berguna dalam pemprofilan penulis apabila sampel rujukan tidak tersedia untuk perbandingan. Sistem pendidikan unik di Malaysia berkemungkinan telah mewujudkan ciri-ciri alografik tulisan tangan yang khusus yang boleh disiasat dalam konteks perisikan. Kajian ini bertujuan untuk menyiasat ciri-ciri alografik tulisan tangan lazim dan boleh membezakan yang boleh dikaitkan dengan latar belakang pendidikan rendah penulis Malaysia untuk perbandingan forensik. Pada peringkat awal, 50 set sampel tulisan tangan tanpa mengira latar belakang pendidikan rendah telah disemak secara teliti untuk menentukan ciri-ciri umum tulisan tangan. Seterusnya, ciri-ciri tulisan tangan yang boleh dikaitkan dengan latar belakang pendidikan rendah (iaitu sekolah kebangsaan, sekolah vernakular bahasa cina, sekolah vernakular bahasa tamil dan sekolah agama Islam) telah dikenalpasti dan perkaitan antara keempat-empat latar belakang tersebut telah dianalisis menggunakan ujian Chi-square dan Regresi Logistik Multinomial (MLR). Ciri-ciri tulisan tangan yang terpilih telah diperiksa pada 400 penulis yang baru dikumpul (100 penulis untuk setiap kumpulan kajian) dalam kajian lapangan. Satu Pokok Klasifikasi dan Regresi (CART) telah ditentukan dan kebolehan ramalan telah diuji menggunakan sampel buta. Daripada sejumlah 189 ciri yang ditentukan pada peringkat awal, 23 daripadanya telah dikaitkan secara signifikan dengan latar belakang pendidikan rendah (nilai  $p < 0.05$ ) berdasarkan ujian Chi-square dan model MLR. Dalam kajian lapangan, ciri-ciri yang



signifikan secara statistik telah berkurang kepada 17 ciri yang terdiri daripada huruf 'B', 'D', 'E', 'G', 'H', 'I', 'p' dan 't'. Sembilan ciri telah diakui mampu membezakan penulis dari satu latar belakang pendidikan daripada yang lain. Melalui CART, lima ciri tulisan tangan yang berkepentingan lebih besar dalam membezakan penulis telah ditentukan, termasuk huruf 't' dengan palang yang ditulis dahulu diikuti dengan lejang menegak, huruf 'B' tanpa lejang awal yang menonjol, huruf 'E' dibina dengan tiga lejang individu, huruf 'E' dengan batang ditulis dahulu diikuti dengan lengan atas, palang dan lengan pangkal, dan huruf 'G' dengan tegasan ditulis dahulu diikuti dengan dagu dan duri. CART telah membolehkan ketepatan pengelasan pada 71.0%. Ujian ke atas sampel buta menunjukkan ketepatan ramalan pada 85.0%. Kesimpulannya, kajian ini telah berjaya menentukan ciri-ciri alografik tulisan tangan yang dikaitkan kepada latar belakang pendidikan rendah penulis Malaysia. Hal ini dapat menyediakan data asas dalam mewujudkan rangka kerja perisikan forensik untuk pemeriksaan tulisan tangan yang akan memberi manfaat kepada penyiasatan kes berkaitan dengan dokumen, terutamanya apabila sampel rujukan tidak tersedia.

**EXPLORATION OF HANDWRITTEN ALLOGRAPHIC FEATURES  
ATTRIBUTED TO THE PRIMARY EDUCATION BACKGROUNDS OF  
MALAYSIAN WRITERS FOR FORENSIC COMPARISON**

**ABSTRACT**

Class characteristics in handwritings is useful in writer profiling when exemplar samples are unavailable for comparison. The unique education system in Malaysia may have established specific characteristic handwritten allographic features that deserve investigation within the intelligence context. This study aims to investigate the common and distinguishable handwriting allographic features attributed to the primary education backgrounds of Malaysian writers for forensic comparison. At the preliminary stage, 50 sets of handwriting samples regardless of primary education background were thoroughly reviewed to determine the general handwritten features. Subsequently, characteristic handwritten features potentially attributed to the primary education backgrounds (i.e., National Schools, Chinese-medium vernacular schools, Tamil-medium vernacular schools, and Islamic Religious Schools) were identified and their associations among the four backgrounds were analysed using Chi-square test followed by multinomial logistic regression (MLR). Selected handwritten features were then examined on newly recruited 400 writers (100 writers for each background) in the field study. A classification and regression tree (CART) was established, and the predictive capability was determined using blind exemplars. From a total of 189 features determined at the preliminary stage, 23 of them were significantly attributable to primary education backgrounds ( $p$ -value  $<0.05$ ) based on the Chi-square test and MLR model. In the field study, the number of statistically significant features were further reduced to 17 features, comprising of

letters 'B', 'D', 'E', 'G', 'H', 'I', 'p', and 't', and nine features were recognised to be capable of distinguishing writers from a single education background from the others. Through CART, five handwritten features carrying greater importance in discriminating the writers were determined, including letter 't' with crossbar written first followed by vertical stroke, letter 'B' with no protruding initial stroke, letter 'E' constructed with three individual strokes, letter 'E' with the stem written first followed by the top arm, crossbar and base arm, and letter 'G' with stress written first followed by chin and barb. It allowed for a 71.0% accurate classification, and testing on blind exemplars demonstrating an 85.0% prediction accuracy. To conclude, this study had successfully determined the handwritten allographic features attributed to the primary educational backgrounds of Malaysian writers, providing the foundation data for the establishment of forensic intelligence framework for handwriting examination, which would be beneficial to the investigation of document related cases, especially when reference samples are not available.

# CHAPTER 1

## INTRODUCTION

### 1.1 Background of the study

Handwriting is a combination of marks, symbols and signs produced from the rotating movements of the arm, hands, and fingers. Handwritings on documents such as cheques, wills, contracts, ransom notes, receipts, and suicide notes often serve as physical evidence in finding lead in crime investigations involving documents. Forensic handwriting examination is a subfield of forensic document examination, which typically concerns in identifying the authorship and authenticity of a handwritten document or signatures on a document by comparing questioned handwritings to the known handwritings. In practice, most forensic document examiners extracts handwriting features from both questioned and exemplar documents via detailed visual examination for comparison, covering features such as arrangement, class of allograph, connections, allograph design and constructions, dimensions, slant or slope, inter-word and intra-word spacing, abbreviations, alignment, commencement and termination, diacritics and punctuation, embellishment, writing quality and legibility, line continuity, line quality, pen control, and the writing movement (Huber & Headrick, 1999).

Similar to other physical evidence such as fingerprints and ammunition recognition in ballistics, handwriting evidence has its own class and individual characteristics (Singh and Raj, 2022; Turnbull et al., 2010). Individual characteristics of handwritings are useful to discriminate and determine the author of a questioned handwriting provided known or exemplar handwriting samples are available for comparison and conclusion rendering. Class characteristics on the other hand could possibly place the author in a

group of writers. This class characteristics or could also be referred to as common characteristics, if known can be useful in extracting demographic information such as gender, age, education background, nationality, and handedness of the writer of a disputed handwriting (Agius et al., 2018). Having this information in crime investigations could be very beneficial in writer profiling, especially when exemplar handwritings are not available, insufficient or of poor quality.

Previously, research studies had been conducted to investigate the class characteristics of writers from different geographic regions. Agius et al. (2018), Al-Hadhrani et al. (2015), Al Maadeed and Hassaine (2014), as well as Turnbull et al. (2010) attempted to extract handwriting features which represented the population of Australian, Vietnamese, Arabic and Polish writers, respectively. It was proven that the nationality of a writer could be reflected in their natural handwriting by visual examination and statistical means. Concurrently, similar studies were also conducted by Saini and Kapoor (2014) and Cheng et al. (2005) to investigate if there was any influence of the ethnic language knowledge to the English handwritings of writers who participated in the respective studies. These studies revealed the existence of ethnic or race specific features to be observed in the handwritings of their respective populations.

Although the presence of common and distinguishable features, which could be attributed to a specific group of writers were proven via past research, the writers who participated in all the mentioned past studies were originated from different geographical backgrounds, and they were taught to write using different copybook systems as well as learned in schools which have different mediums of instructions (Valiatia et al., 2016; Agius et al., 2018, Turnbull et al., 2010; Cheng et al., 2005).

Therefore, such information could be useful to compare the handwritings of writers from two nationalities for forensic intelligence purposes. The advantages and relevance of such studies had been explored and discussed across different countries but not in Malaysia *per se*. Thus, investigation of the common and distinguishable handwriting characteristics among Malaysian writers shall be initiated for forensic comparison.

To date, there was only one research conducted in Malaysia, concerning on the exploration of class characteristics present in disguised Malaysian handwritings more than ten years ago. In the study, Mohamed et al. (2010) examined the handwritings of writers from the three major races in Malaysia, namely Malay, Chinese and Indians, where the handwriting features such as script type, letter size, slant, angularity, alignment and word spacing were explored, instead of features pertaining to the formation of letter such as the stroke sequence, number of pen lifts, formation of letters, morphology of apex and vertices as well as initial and terminal stroke. Since the main interest of this study is to identify the class characteristics of handwriting attributable to a primary education background, it is important to consider elements of style, especially features related to the connections, letter design and construction in this research. This is because, according to Huber and Headrick (1999), allographic design and letter construction are known to be influenced by different writing systems or copybook systems. Apart from that, Mohamed et al. (2010) only discussed on the influence of racial background on the handwritings of their writers and the influence of primary education systems in Malaysia on the English handwritings was not taken into consideration.

Malaysia has a unique design of curriculum with different copybook systems and different medium of instructions in school, where parents are given the liberty to choose the primary learning systems for their children. Generally, the National Schools, Chinese National Type Schools (SJK(C)), Tamil National Type Schools (SJK(T)) and Islamic Religious Schools are available for enrolment (Sivalingam, 2020; Abdul Hamid, 2017). It was suggested that the primary educational stage is the handwriting formative stage. Therefore, exposure to different learning systems could contribute to the adaptation of specific writing habits in an individual (Koppenhaver, 2007; Levinson, 2002). As to initiate the effort to explore the class characteristics of handwritings among Malaysian writers, this present study focused on identifying the common and distinguishable handwriting characteristics attributable to the primary learning systems in Malaysia. The class characteristics identified via this study, could be used to design a screening framework for investigative and enforcement purposes to aid future crime investigation, especially when exemplar samples are not available for comparison purpose in authorship determination.

## **1.2 Problem statement**

In forensic science, forensic handwriting examination plays a role in identifying the author of a questioned handwriting. In most cases, such examination involves comparison of an unknown writing sample with samples from a known writer based on the assessment of similarities and/or differences between these samples to address court query (Huber & Headrick, 1999; Koppenhaver, 2010). Such comparison is mandatory during forensic investigation in criminal procedures or civil disputes, but only possible when comparable writing samples are available to forensic document examiners. In cases where suspect or victim is unknown or in the absence of

comparable handwriting samples, such as untraceable parcels sent to individuals or written documents received from unknown senders, the application of conventional forensic handwriting examination method using known and suspect samples become impossible. In view of this, even if there is no known writing sample is available for comparison or available but lacking in quality or quantity, an expansion on forensic handwriting examination to profile the writer of the questioned handwriting can still be done. The profile of writers could then be utilised for investigation by narrowing down the possible group of writers (Panicker et al., 2021; Sharma et al., 2023; Sahu et al., 2017). This could provide a wealth of information to be integrated into a forensic intelligence framework in document related fraud (Agius et al., 2018).

In cases involving similar scenarios mentioned above, it is still possible to determine important information in reference to the writer, such as education background, gender, ethnicity, age, and handedness. Multi-lingual society of Malaysia with different learning systems provides opportunities to explore background features of handwritings in Malaysian population. Results reported in similar research studies conducted in the past (Cheng et al., 2005) in disparate geographical region with dissimilar copybook systems and curriculum could not be readily applicable in local investigation context as these parameters could vary among writers from one geographical region to another. Likewise, writers who are exposed to different copybook systems may adapt different habitual handwriting features (Valiatha et al., 2016).

Most people learn to write by copying letter formations through copybook at a young age. Constant practicing and repetition of letter and word formations in an individual has made writing becomes a subconscious act. Malaysia is probably one of the most



unique countries in the world, where the primary school systems are categorised into four different educational systems, namely the Malay-medium National Schools, Islamic Religious Schools, as well as the non-Malay National type Schools or also known as vernacular schools, which uses Chinese language and Tamil language as medium of instructions. All these schools, except Islamic Religious Schools, enrol students regardless of their ethnicity and language backgrounds. The variations in academic backgrounds, or more specifically, the educational learning systems by Malaysians are believed to have influence in their handwriting formation while writing and this remains unexplored.

### **1.3 Research Questions**

Forensic document examiner compares unknown writing samples to known documents to determine the authors of documents involving fraud and forgery in criminal and civil cases. It is seen that forensic document examination could also provide alternate information about an author in cases where known samples are unavailable or inadequately available. Hence, the questions pertaining to the possibility of handwriting characteristics of Malaysians to be utilised for forensic intelligence, which are intended to be answered in this research are as follows:

1. What are the common and distinguishable handwriting characteristics among Malaysians from different primary education backgrounds?
2. How does primary education background influence the handwriting features among Malaysians?
3. How could the identified handwriting characteristics among Malaysian's aid in predicting writers based on their respectively educational background?

## **1.4 Objectives**

### **1.4.1 Main objective**

To explore the handwritten allographic features attributed to the primary education backgrounds of Malaysian writers for forensic comparison.

### **1.4.2 Specific objectives**

To achieve the main objective, specific objectives of the study are set as follows:

- i. To identify the common and distinguishable handwriting characteristics of Malaysian writers attributable to respective primary education backgrounds.
- ii. To determine the possible influence of native scripts taught during primary schooling years towards the formation of handwritten features, which could be attributed to different primary education backgrounds.
- iii. To establish a screening framework for the prediction of the educational backgrounds of Malaysian writers.

## **1.5 Scope of Study**

The study focused on identifying the common and distinguishable handwriting characteristics of Malaysian writers from different primary education backgrounds. Therefore, other potential influencing parameters, such as gender, age, ethnicity, and handedness were not covered in the present study and shall possibly be extended in future work. Additionally, this study examined all 26 upper and lowercase letters of English handwritings, and no numerals were considered for comparison.

Since the beginning of Daubert era, the need for objectifying handwriting evidence has increased. For this purpose, recent research studies mainly focused on developing semi-automated or automated computer-based tools in extracting features from the digital images of handwriting for authorship determination purpose (Risinger, 2000). The method requires pre-processing of image, which involve skeletonization and binarization of the handwriting digital images (Srihari et al., 2012). Some researchers (Gattal et al., 2023) process the digital image of the handwritings to extract features related to the curvature, contour and texture of the handwriting sets before proceeding to the comparison step. This process was reported to have caused loss of features and introduction of artefacts which could affect the identification accuracy of automated software (Marquis et al., 2006; Pervouchine & Leedham, 2007). To retain the conventional method and to prevent loss of important handwriting features such as terminal stroke and initial stroke morphology as well as stroke sequence, letters are visually examined and subsequently quantified using statistical method without processing the digital image of handwriting samples. All the features extracted and considered for the purpose of this study were validated by certified questioned document expert formerly attached with Document Examination Division of Department of Chemistry Malaysia (JKM).

## **1.6 Significance of Study**

By identifying the common and distinguishable handwriting characteristics of Malaysian writers from different primary education backgrounds, this study will provide the fundamental idea of the handwriting characteristics within Malaysian population as well as insight whether the learned educational systems during copybook age have been retained in the handwriting or diverged from the taught writing styles.

Such knowledge will help to solidify the foundation of Malaysian handwriting, and subsequently enable the determination of class characteristics of handwriting which correspond to Malaysian population. The data will then serve as the initial data for a forensic handwriting intelligence framework. An understanding on handwritten pattern among Malaysian's writers and the collation of information of a source or an author coming from a particular group or background education system would be beneficial to the investigation of document related cases, complementing the conventional forensic document examination that can then be applied to identify and confirm a particular individual once the known writing sample is available.

In this regard, the establishment of a screening framework could assist investigators, especially those who are not trained and certified to examine handwritings, to track the demographic background of Malaysian writers. From the forensic investigation perspectives, the framework could provide information to the law enforcement authorities, especially in cases where comparative document is absent, and no suspect was identified. Even if perpetrators managed to cross international borders into neighbouring countries like Singapore, the screening framework might also be useful to even distinguish writers of similar ethnicity but of different nationality due to the uniqueness of the country's learning system. The study also provides knowledge about the criminal activity to allow forensic science to participate more extensively in the disruption and deterrence of crime, by gaining more information obtainable from a person's handwriting. It shall improve the crime scene investigation practice and enhance the evidential value of forensic document examination in any cases involving documents, or more specifically handwriting.

## **1.7 General Approach of Study**

The present study was a descriptive study, focusing on the extraction of handwriting features, and determination of the frequency of occurrence of common and distinguishable handwriting characteristics among Malaysian writers from the four primary education backgrounds. Natural handwritings from writers were collected using a data collection kit where they were required to copy the source document thrice on the blank A4 paper. Subsequently, all the handwriting samples were visually examined and coded by assigning binary values.

This study was subdivided into five different phases. During the preliminary study, handwritings from 50 writers were randomly collected regardless of their education backgrounds, age, and ethnicity background to observe and extract all prominent and frequently occurring handwritten features among the handwritings of Malaysians. This is a crucial phase incorporated in the study design to avoid omitting prominent common and distinguishable handwriting features within the population. This methodology was not clearly explained or seemed to be employed by other similar researches, which was conducted in the past such as Agius et al. (2018), Al Maadeed and Hassaine (2014), and Cheng et al. (2015).

For the pilot study as the second phase, handwritings of 120 writers, 30 writers for each primary education background (i.e., Group A for National School, Group B for SJK(C), Group C for SJK(T) and Group D for Islamic Religious School), were examined to determine the handwriting allographic features which could be attributed to the respective primary education background. In this phase, handwriting allographic features selected from the preliminary phase were observed and coded. Frequency of

occurrence of all observed features were statistically determined to establish if there is any association among writers from the four different primary education backgrounds. Features showing significant association ( $p$ -value  $<0.05$ ) were tested using multinomial logistic regression (MLR) Model, adjusted with confounding variables. Based on the results of MLR analysis, the features attributable to a particular primary education background are identified.

In the next phase, handwritings of 400 writers (100 writers for each primary education background) aged between 18 to 60 writers representing the general population of Malaysian writers were examined. With a similar methodology carried out in pilot study, the handwritten features that showed consistent and statistically significant results were considered to establish the screening framework. A screening framework was then developed using statistical method known as the Classification and Regression Tree (CART) by considering handwriting allographic features determined from the previous phases. Lastly, the screening framework was tested through a blind test involving 20 randomly selected handwriting samples and the respective primary education background of the blind samples was determined. The prediction accuracy of the screening framework was also determined and proposed. A summary of the five phases involved in this study is outlined in the Figure 1.1.

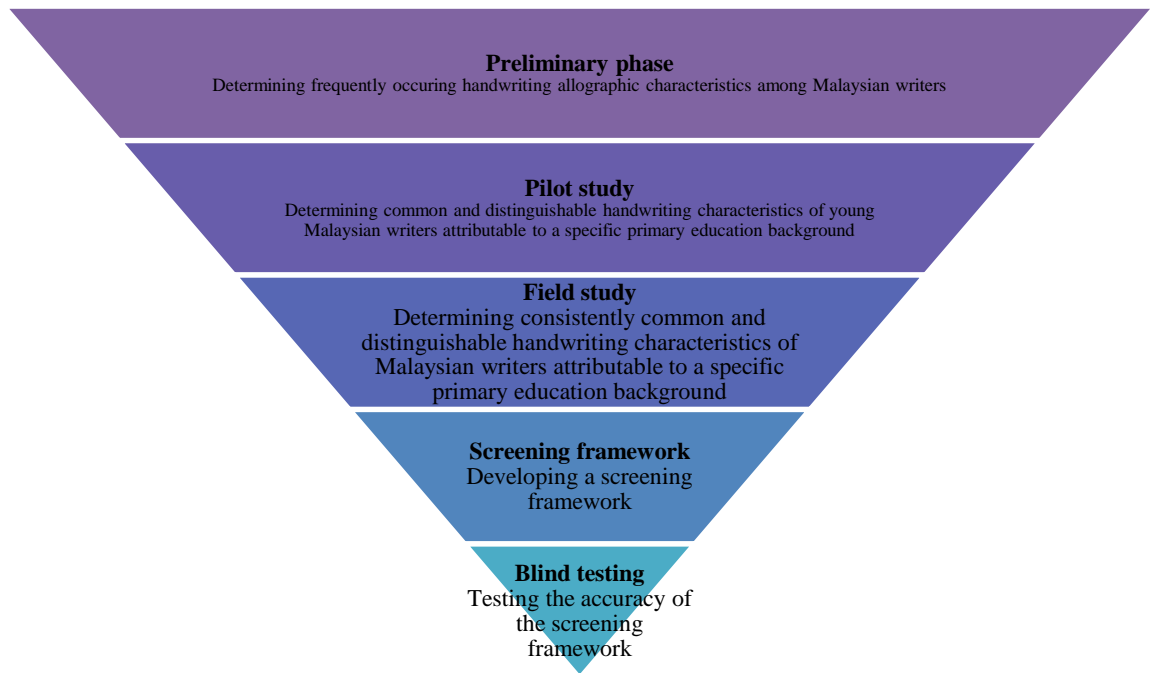


Figure 1.1 Summary of the five phases in the study

## **CHAPTER 2**

### **LITERATURE REVIEW**

#### **2.1 Handwritings**

Handwriting is a system comprising of marks, symbols or signs which portrays the utterance of a language. They can be taught to or adapted by an individual using copybook or adapting a letter, mark or symbol written by someone else through observation (Morris, 2020; Singh & Raj, 2022). Writing is a function of brain which simply uses hand, mouth, foot, or other body parts as a medium to carry out motor instructions generated by the brain (Morris, 2020; Osborn, 1920). In other words, it is done through a combination of rotating movements of the arms, hands, and fingers (Osborn, 1920; Simner *et al.*, 1996) which is controlled by a particular region of the cerebral cortex of the brain, the posterior part of the middle frontal gyrus which is also known as the ‘writing centre’ in the human brain (Caligiuri and Mohammed, 2012).

Multiple motor and sensory neurons throughout the central and peripheral nervous system play important roles in controlling the precise movement of human body parts involved in writing (Caligiuri and Mohammed, 2012). During the course of writing, the palm of the writer rests on the writing surface, his or her wrist flexed or bent inwards, so the fingers is positioned towards the writer. Contractions and relaxations of muscles according to brain signals produces different upstrokes and down strokes resulting in unique handwriting styles or patterns (Morris, 2020). The muscular contraction and relaxation give rise to a combination of hand movements, which influences the writing skill and writing speed of the author (Osborn, 1920).



At early age, children learn how to write by paying attention to the formation of letters through the process of drawing (Caligiuri and Mohammed, 2012). As one grows, through practice, attention shifts from the letter formation process to the letter itself where letters are written subconsciously instead of drawn (Caligiuri and Mohammed, 2012; Singh and Raj, 2022). The process becomes more skilful, automatic, and smoother. At this stage, the handwriting of an individual may deviate from their learnt copybook style leading to the development of individual characteristics (Singh & Raj, 2022).

According to literatures, handwritings are seen to undergo changes over time (Durina, 2016; Caligiuri and Mohammed, 2012; Koppenhaver, 2002; Osborn, 1920). One undergoes four stages of handwriting development in life (Huber and Headrick, 1999). The first stage is called formative stage, second stage is called impressionable or adolescent stage, third stage is called the mature stage and finally the degeneration stage (Huber and Headrick, 1999). It was said that the process of writing will be under conscious control during the first two stages and becomes involuntary as it progresses to the next two stages (Huber and Headrick, 1999). The structure, fluency, and consistency changes in the first stage, while letter formation or style with the of desire to imitate influences of the second stage (Huber and Headrick, 1999). Handwriting characteristics in the third stage is said to be more consistent (Huber and Headrick, 1999). During the fourth stage, handwritings may degenerate, where line tremors, inconsistent shapes, slopes, and sizes of letters with poor skill and writing quality may be observed (Huber and Headrick, 1999). This is mainly due to the neurophysical deterioration that one undergoes while they age. Changes are most drastically seen from childhood (six to twelve years of age) to adolescence (twelve to twenty years of age)

until a person reaches adulthood (twenty to sixty years of age) where graphic maturity reaches plateau (Koppenhaver, 2002; Osborn, 1920). In other words, changes in handwritings becomes slower after it attains graphic maturity and begins to accelerate again during the declining years (Levinson, 2002).

At early teenage years, individuals may add extra features to their handwriting trying to imitate someone else's handwriting or even apply shortcuts in the way letters are usually written (James et al., 2014). When graphic maturity is attained, neuromuscular movement of hands becomes more habitual where the basic handwriting styles are established and continue to be similar throughout a person's life (James et al., 2014; Koppenhaver, 2002). Thereafter, handwriting may start to deteriorate as a person age (Allen, 2015; Koppenhaver, 2002). The handwriting skill and the graphic maturity of a person who writes frequently at a quotidian basis is also discussed to be greater than a person who has higher education level but do not practice handwriting in their daily life (Morris, 2020).

Valiatha et al. (2016) reported that writers between the age of 21 to 59 years old, who participated in their study, exhibited higher frequency of graphic peculiarities in their handwritings. In another study conducted by Upadhyay and Singh (2017), focused on investigating the effect of age in the handwritings of female writers who participated in the study, it was proven that almost all writers between the age of 20 to 40 years of age exhibited smooth and perfect line quality. Line quality is reported to be less smooth in 35.0% of writers who are between 40 to 50 years old, whereas marked deterioration in the line quality was observed in the handwritings of writers above 60 years old. This is mainly due to the lack in motor coordination between the brain and muscles (Upadhyay

& Singh, 2017). Thus, to eliminate the possible effect of age factor in the habitual pattern of an individual's handwriting, only writers between 18 to 60 years of age were considered in this study.

## 2.2 Factors affecting handwritings

Individuality and changes in handwriting can be influenced by many factors. Morris (2020) have established several major factors that could influence the letter formation, namely the mechanical factors which includes pen, ink, writing material and writing surface, writers' graphic maturity, writers' relative writing speed, learned writing system, visual sensitivity and impressionability, memory of forms, characterological factors and psychopathological factors, vanity, affection and desire to imitate others, general intelligence, subject matter concentration, temporary or permanent physical impediments, as well as temporary emotion or excitement as described in Table 2.1.

Table 2.1 Major factors influencing letter formation established by Morris (2020)

<b>Major factors influencing letter formation</b>	<b>Description</b>
Writing instrument, material, and surface.	A defective writing instrument may affect the writing fluency. Rough writing surfaces can cause tremors which would influence the line quality
Graphic maturity of writer	A graphically immature writer may write a letter by constructing individual strokes with more pen lifts. When the maturity increases, the letter may be written in one continuous stroke as the writing act become subconscious. At the next level of maturity, strokes between letters forming a word may be connected to each other. Graphic maturity can also be a good indicator of disguised handwriting.

Table 2.1 continued

Writing speed	Formation of up and down strokes of a letter could be affected by the individual's very own relative pressure habits. Relative pressure is defined as the differences between the writer's writing pressure when constructing an ascending stroke and a descending stroke.
Learned writing system	Habitual features related to letter formation could highly vary between an individual who is taught the cursive writing system and the hand-printed system
Visual sensitivity	Typically, a writer writes what he or she sees during their learning stage.
Memory of forms or vanity, affection and desire to imitate others	Formation of letters by an individual could be influenced also by the handwriting formation of another writer. A writer who likes the way a letter is written by another writer, may adopt the writing habit into their own handwriting. Some writers even consciously copy, any letter designs which they find striking.
Characterological and psychopathological condition	Personality and the state of mind of an individual could be reflected in their handwriting.
Chronic physical impediments	Depending on the nature of impediments, if it affects the central nervous system of a person, marked deterioration in the quality of handwriting can be seen.

Additionally, Koppenhaver (2002) and Harralson & Miller (2013) also mentioned that time span, health blindness, mental illness, drugs and medications, as well as the consumption of alcohol could also influence changes in handwriting to a certain extent. Personal taste, artistic ability, musculature, and nerve tone of an individual might also give a consequential effect to the individuality of handwritings (Koppenhaver, 2002). Although various external factors may alter or modify the handwriting of an individual to a certain extent, it was suggested a writing shall not deviate much from the basic handwriting styles or patterns, thus retaining the writer's individuality and handwriting habits.

### **2.3 Handwriting as physical evidence**

The wide usage of papers in personal and legal affairs has brought to the necessity where the authenticity of the information on a paper or document must be ensured before used for its respective purposes. Cheques, wills, contracts, ransom notes, draft order, receipt, certificates, and suicide notes are some examples of documents involving handwriting and signatures (Osborn, 1920; Tilstone et al., 2006). The handwritten details on the aforementioned documents may be forged, disguised, or altered for criminal intentions such as threats, fraud, identity theft, elderly abuse, financial crime or white-collar crime, medical malpractice, insurance fraud and contract disputes (James & Nordby, 2014). The Lindbergh child kidnapping case was the first case which acquired handwriting verification of Hauptmann who was suspected to be the author of ransom notes back in 1935 (Roensch, 2004).

The penmanship system begun in the 1500s (Koppenhaver, 2002). The system determines the class characteristic of a person's handwriting. In 1920, Albert S. Osborn first initiated research and developed methodology to examine questioned document after the Rice Will Case in 1903, where he was testified in court to prove forgeries on cheques and wills. The effort of Osborn was later continued by Ordway Hilton since 1956. Later in the 20<sup>th</sup> century, due to an increase in the use of business documents and related transactions, there was a rise in the demand of forensic document examination expertise. Albert S. Osborn and colleagues established a methodology applying scientific principles in document analysis (Osborn, 1920). The methodology involves preliminary examinations of the documents, photographing the documents in question and comparing the documents with exemplar documents, are still accepted in court, and

being widely practiced by most document examiners including forensic document examiners in Malaysia.

## **2.4 Forensic Document Examination**

Forensic document examination or also known as questioned document examination is a subfield of forensic sciences, in which its objective is to determine the authenticity and the authorship of a document in dispute (Bell, 2008). Examination is conducted by document examiners to determine details such as the author of the document, the date when the document was produced, addition or erasure to its content, originality of the document, as well as what makes up the document such as the ink and the paper material (Tilstone, 2004; Bell, 2008).

### **2.4.1 Forensic Handwriting Examination**

Forensic handwriting examination is a part of forensic document examination, which concerns in identifying the authorship and authenticity of a handwritten document or signatures on a document by comparing the questioned handwritings to known handwritings (Huber & Headrick, 1999). Handwritings are unique and even the same writer could not produce the same handwriting twice (Ellen, 2003). Handwriting, as physical evidence, is simply a combination of class and individual characteristics, which gives rise to a unique individual design (Valiatia et al., 2016).

There is existence of intra-writer variation or natural variation in handwritings which is typically a small range of differences that can be present within genuine writings of the same person due to factors such as speed of hand movement and writing surface (Ellen, 2003). Natural variation does not usually deviate from the features which arises from

an individual's natural writing habits. Even with the presence of natural variation, the habitual features of an individual are usually consistently present in their handwritings, making them highly exclusive and unique (Gupta et al., 2017; Thomas & Rajan, 2019). Thus, the presence of natural variation makes superimposition of scripts written by the same person impossible. Identifying natural variation is important to a handwriting examiner so that it is not confused or misinterpreted as forged or disguised handwriting, often leading to false match error (Thomas & Rajan, 2019).

The *United States v. Starzecpyzel* case is the first case where the reliability of forensic document examination expertise was questioned. The judge, McKenna, examined the opinion delivered by the document experts in this case and rejected it as it did not comply to the Daubert's standards. The standard states four guidelines, namely, *testability, peer-review and publication, error rate* and *general acceptance* for the admissibility of expert witness evidence in court of law (Fournier, 2016). Since then, Daubert's Standard is frequently mentioned in literatures and studies in recent years were more focused on identifying the writer of handwritings or handwritten scripts either by automated or semi-automated means using statistical, image processing and computer-based tools (Marquis et al., 2006; Siddiqi & Vincent, 2010; Srihari et al., 2002; Srihari et al., 2008; Said et al., 1998; Gattal et al., 2023) for authorship identification purposes. This could be due to the need to objectively examine handwriting evidence so that it could be quantified, and its error rate was known.

As much as individual characteristics are important in authorship determination, class characteristics of handwriting are also given attention by the field researchers. In some studies, the class characteristics in handwritings were found useful in tracking

background information of an unknown writer including the ethnicity (Saini & Kapoor, 2014; Saini & Kaur, 2018), gender (Panicker et al., 2021; Sharma et al., 2023), race (Cheng et al., 2005), nationality (Al Maadeed & Hassaine, 2014; Agius et al. 2017), age (Rizvi et al., 2014; Thomas & Rajan, 2019; Shin et al., 2022), handedness (Morera et al., 2018), learned writing systems and foreign language knowledge (Mehrabi, 2014). This information can be used by intelligence-led policing to aid in decision making, planning, strategic targeting, and crime prevention (Angel & Kelly, 2020). The background information extracted from handwritings could fill the information gaps and may provide clues pertaining to the suspects in crime investigations (Angel & Kelly, 2020).

As early as 1989, Rimmer and Totty had addressed the issues faced by questioned document examiners when analysing documents related to international fraud, where exploring the handwritings of writers from different nationality could be helpful in investigating related cases. This was because when a perpetrator from one country committed a crime in another country with insufficient exemplar samples, identifying the perpetrator can be challenging. Thus, studying the demographic background of the writer based on their handwritings originated from different geographic settings can be a complimentary contribution for forensic intelligence purpose (Agius et al., 2017), whereby, even without exemplar samples, extracting handwriting features attributed to the nationality of the author can still be possible and this could provide leads to investigation. It can also be useful in identifying connections between crimes, nationally and internationally (Deviterne-Lapeyre, 2020).



Valiatia et al. (2016) conveyed that it was challenging to identify learning systems based on an individual's handwriting as one is exposed to different learning systems and teaching methods during their schooling days. The authors addressed that it was challenging to identify and classify the handwriting features, which could be attributed to a group of writers and justified that this could be mainly due to lack of knowledge on subject's background and due to the lack of database for reference. The study conducted were very much applicable in Malaysian setting, where there are several streams and choices of schooling systems.

#### **2.4.2 Individual and class characteristics of handwriting**

Handwritings as forensic evidence have both class and individual characteristics. Individual characteristics are those handwriting features which can be used to discriminate one writer to another distinctively, while class characteristics are those features that can locate a writer in a particular group of writers (Agius et al., 2017). Class characteristics were said to have developed from the learnt copybook style during the age when a person first learned how to write while individual characteristics is developed from the writers own subconscious writing habits, which does not change over time (Singh and Raj, 2022).

When a characteristic found in a handwritten script reoccur more than 25.0% in a population, it is considered a class characteristic (Turnbull et al., 2010). Some studies such as the one conducted by Valiatha et al. (2016) accepts a frequency threshold of 10%. The aforementioned 'features' included both qualitative and quantitative elements which can be extracted by forensic document examiners during handwriting and signature examination.

Huber and Headrick (1999) had established 21 discriminating elements (refer Figure 2.1 for the list of elements) which are vital to distinguish handwritings and signatures (refer Table 2.2 for the description of each element). These elements are further categorised into four different categories, namely the elements of style, elements of execution, elements attributable to all writing habits and elements related to the combination of writing habits. Elements of style are adapted by writers from their copybook stage or vocational learning process whereas elements of execution are the personal idiosyncrasies incorporated into writings depending on the writers' personal skills and personal preferences. The later was said to have higher contribution to the individuality of handwriting and signatures (Huber and Headrick, 1999). Elements attributable to all writing habits are in fact not elements related to the class or individual characteristics of handwriting. Instead, they are elements which could be naturally found in every set of handwriting. Likewise, elements related to combination of handwriting habits could vary depending on the space availability on writing material (Huber and Headrick, 1999).

# Handwriting Discriminating Elements

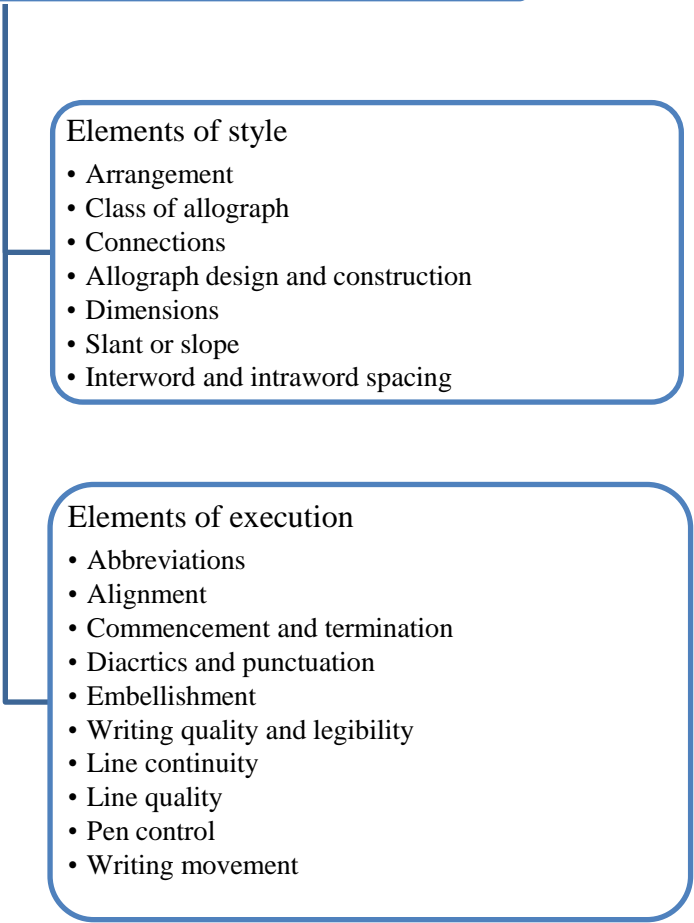


Figure 2.1 List of handwriting discriminating elements taken from Huber & Headrick (1999)

Table 2.2 The 21 discriminating elements taken from Huber and Headrick (1999)

No.	Discriminating elements	Definition	Importance in handwriting examination
<b>Elements of style</b>			
1.	Arrangement	Cluster of features which depends on the artistic ability, sense of proportion and instruction received.	<ul style="list-style-type: none"> <li>The position and balance of handwritings and signatures in relation to the sheet margins can vary from one individual to another.</li> </ul>