Original Article

International Journal of Forensic Science
Volume 1 Number 2, July - December 2018

A Mathematical Approach to Validate and Correlate the Effect of Age on Handwriting Using Quantitation of Individual Characteristics

Mohit Soni[1], Faray Jamal[2]

Abstract

Handwriting is legible text created by using any writing instrument on a writing surface. It is a coordinated work done by an individual's intellect and muscles. Aging, affects the brain and the body both. Therefore, it affects handwriting. With time experts have come up with varied approaches to decipher handwriting and the changes that come in it. This work proposes quantitation of individual characteristics, namely hiatus and proportion, to be employed to derive to a co- relation between the time-elapsed and the percentage change observed. A pattern has been discovered. The study was performed on twenty subjects above the age of 28. The time gap in the samples observed was 15 years. The amount of change coming in authors' handwriting after the same amount of time had passed, was found to be similar.

Context: Questioned Document Examination

Aim: To establish effect of age on handwriting and to establish a mathematical pattern to the observed changes, in a sample population

Results: Quantized individual characteristics are found to change in a mathematical pattern

Keywords: Graphology; Proportion; Hiatus; Baseline Alignment; Class Characteristics; Individual Characteristics.

Introduction

Handwriting is text created by an individual using a writing instrument which can be a pen or a pencil on any writing surface. When speaking analytically, handwriting is referred to as an indicator of personality traits which is represented by a neurological pattern of the brain [1]. Putting it more simply, our brain forms the character as a result of habit which is developed over a period of time thus imparting individuality to a person's handwriting. Our brain guides the movement of our hand. Whatever we put on paper is a two-way circuit that occurs between the brain and the motor reflex muscles of hands.

Handwriting is a gateway to the subconscious. A handwritten document is an amalgamation of psychological states of mind enacted by physical motor control, copied on a writing surface. Needless to mention, these are extensively utilised for psycho-analysis and forensic investigations alike.

Forensic analysis of handwriting traditionally answers two questions. These are to establish authorship and source of the document in question. The determination for authorship is performed in comparison-based analytical tests, performed by employing individual characteristics found in every author's handwriting. This may also consider additional clues left by the perpetrator. The determination for source of the questioned document is performed by analysing the writing surface, the writing instrument and the writer,

Author's Affiliation: [1]Associate Professor, Division of Research and Development, Lovely Professional University, Jalandhar, Punjab 144411, India. [2]Student, Department of Forensic Science, Mody University, Lakshmangarh, Rajasthan 332311, India.

Correspondence and Reprint Requests: Mohit Soni, Division of Research and Development, Lovely Professional University, Jalandhar, Punjab 144411, India.
E-mail: mohit.24385@lpu.co.in

if known. Additional clues may aide this too. Psychological markers studied under Graphology, provide directions to investigations [10].

Ever since the onset of this science various individual characteristics have been employed by forensic scientists to compare questioned documents [5]. Several scientists have given their own set of forensically relevant individual characteristics [1,2,11]. The handwriting of an individual cannot be consistent owing to natural variations [2]. Individual characteristics are those features of an individual's handwriting that do not change in spite of natural variations. These have been surmised below:

The set of characteristics that have been considered are presented as Table 1. Handwriting of an individual changes due to several factors [2]. Changes in handwriting may occur due to:

1. Variations in geography
2. Variations in writing surface and writing instruments
3. Intoxication
4. Age

Due to all the above reasons, individual characteristics are indeed observed to change, but with a degree of consistency [3]. For example, when a person is under the influence of alcohol, the spacing between his letters/words increases [2,11]. But it has been observed that the consistency, with which this change occurs, is symmetrical. Recent studies have pointed out that this change is more dependent on the amount of alcohol consumed and the body-mass index of an individual than the Individual himself. This paper takes this idea forward and attempts to correlate the change in handwriting with age.

Table 1: Individual Characteristics of Handwriting

Individual Characteristic	Definition
1. Baseline Alignment	Relationship of the formation of the letters/words to the baseline of a questioned writing
2. Slant	this refers to the angle of inclination of writing from the baseline. It maybe "forward" i.e. leaning to the right, or "backward" i.e. leaning to the left
3. Skill level	An individual with a high skill produces writing that is fluid, rhythmic, artistically embellished and is aesthetically pleasing to the eye. Whereas an individual with a low skill level produces a product that is hesitating and is slowly executed
4. Form	Form is the pictorial representation of a letter or writing movement.
5. Movement	Manner of movement of the writing instrument (either a pen or pencil) to form a letter/word.
6. Proportion	Symmetry of an individual letter.
7. Height, Ratios and Proportions	Comparison or correlation of the height of one letter or letter segment to another letter, usually within the same word or signature
8. Pen Lifts	An author often lifts the writing instrument from the writing surface, usually in the midst of a word or a signature.
9. Loops	Loops are generally found in cursive handwriting styles. These maybe symmetrical or asymmetrical
10. Embellishments	It refers to the corrective after stroke and is usually seen at the beginning of the document but can be found throughout the writing.
11. Entry/ Exit Strokes	Entry and exit strokes of letters or typical words are habitual movements and therefore may serve as identifying characteristics.
12. i-dots / t-crosses	A portion of writing as small as innocuous as an "i" dot may at times become a prominent identifying characteristic. Even the formation of the shape of the dot becomes unique.
13. Retracing	Retracing is the process where the author re-inks the written portion of the line, usually in the opposite direction. Such as a downward movement followed by an upward movement over an existing line. Though it is found rarely but creates individual trait of identification.
14. Format	The format of a disputed document may additionally be an identifying characteristic as it depicts the way in which the writer puts common details such as dates, abbreviations, page numbers etc. this may produce individual traits for comparing authors.
15. Spacing	Spacing between adjacent words (hiatus) or even letters (in a non-cursive script) in a questioned writing may again display habitual characteristics of a specific writer. This varies among individuals.
16. Case	The writer's use upper case or lower case letters in place of each other thereby making case a unique characteristic in handwriting.

The methodology adapted for the aforementioned purpose is mathematical. Out of all the 16 individual characteristics, it was observed that characteristic number 6 and 15 (in Table 1) are quantifiable. This means that these two characteristics are measurable. For this study, proportion and spacing have been considered.

Effect of aging on an author's handwriting has

been studied since years [1,2,10,11]. All the activities that a person does are governed by the brain in coordination with the spinal cord and muscles. The brain grows incredibly and tremendously at young age and starts shrinking and degenerating as a person gets older. Handwriting is among the activities that stimulate the better functioning of the brain. When a person is engaged in writing, a number of regions of the brain are involved which work simultaneously to yield the desired result. With the learning process at early age the person acquires knowledge that lasts for a lifetime [5]. With age the brain shrinks and degenerates. As a person hits his later twenties, the neurons start to loosen their proper stimuli and thus reflexes are not generated so quickly [6]. The change is significantly noted in the handwriting of the person which steadily and progressively changes as the person grows. The extent of this change is dependent on different factors, namely skill level, health and the stage of life of the author. Skill level increases as the person grows from infant to young adult, thereafter with lack of practice and irregular writing habits, the skill level gradually decreases. Health of the person plays an important role as well. Be it physical health or mental health, the brain activity is slowed down in such cases. The prime focus of the brain is to prepare the body to fight the disease, thus other reflexes are not well coordinated [5]. As age progresses the brain activity falls. Age significantly affects sensory processing and handwriting pressure along with temporal and spatial measures. In old age the writing is characterized by either lack of control of the writing instrument or tremors [1]. The strokes made by the writing instrument tend to be rough and written with immense pressure which breaks the continuity of the line.

To surmise, the deteriorations produced in the writing caused due to age are [1]:

1. Loss in fluency (skill) or in the smoothness of curves and lines
2. The appearance of fine tremors
3. Deterioration in the quality and structure of letter forms
4. Irregularity of word and letter alignment, inter-word and inter-letter spacing and width of loops
5. Inconsistent entry and exit strokes
6. Prominent occurrence of erratic strokes
7. Reduction in pen pressure

Traditional literature confirms that a change in hiatus (inter-word spacing) and proportion does occur with age. How much is this change? Is the change dependent on external factors? Is there a general trend in the changes that come in an author's handwriting? Are these trends generic? Is there a pattern? This paper tackles with such patterns in changes bought about with age. The study has been performed on a sample population of 20. All subjects were above the age of 18 at the time their first samples were authored and are at least 30 years old at the time of writing of this paper. The study is gender neutral.

Procedure

For this study, samples are collected from 20 subjects, under two separate time frames. Samples from the present are in Set P. Each subject is denoted by a number. Set P has 3 samples each from these twenty subjects. Subjects are denoted as P1, P2, P3, P20. Each subject Pn was requested to submit 3 samples each, from the same time frame. These are denoted by generic notation Pn', Pn'' andPn'''. To surmise:

$$P = \{P_1, P_2, P_3, \ldots, P_{20}\}$$

$$P_n = \{P_n', P_n'', P_n'''\}$$

Each subject was requested for a handwriting sample from 10 to 15 years ago. These were aggregated in Set O. Set O consists of 1 sample each from each subject. These are represented below:

$$O = \{O_1, O_2, O_3, \ldots, O_{20}\}$$

The time lapse between P_n and O_n ranges from 10 to 15 years.

In the first step, a baseline needs to be defined for all samples. Baseline by definition is an imaginary line connecting the lower most ends of the body of all characters, in a line. On a ruled sheet, a baseline is already drawn for the author. On plain sheets, on the other hand, a baseline can be artificially drawn following the above definition. Traditionally, a character can have one, two or three parts to it.

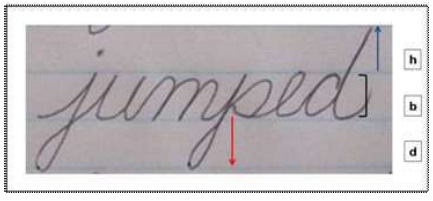


Fig. 1: Three parts to any Character

Figure 1 shows how characters can have three

distinct parts to their form. *"h"*is the height of a character, *"b"*is its body and *"d"* is the depth. As stated, characters can be made of one part (for example the letter *'u'* only has a body*"b"*), two parts (for example the letter *'p'* has a *"b"* and *"d"*) or three parts (for example the letter *'k'* may have*"b"*, *"h"* and *"d"*). Based on these clarifications, a baseline was dropped in all samples. This is depicted in Figure 2(a). In samples with no baseline present, the same was drawn considering the definition stated above. This is depicted in Figure 2(b).

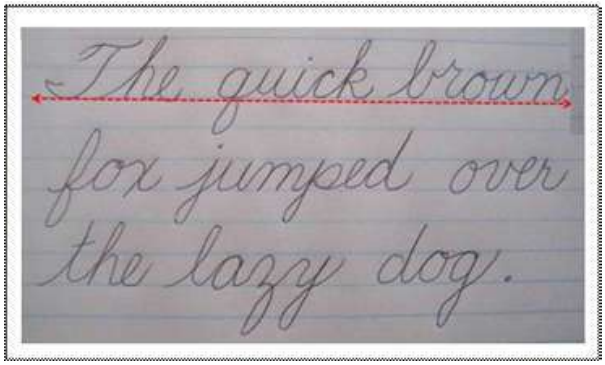


Fig. 2(a): Dropping a baseline

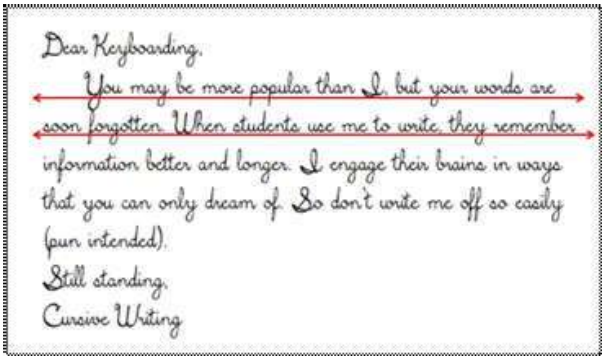


Fig. 2(b): Dropping a baseline on a non-ruled surface

The second step is calculating proportion. Measurements are done using a conventional sub-millimetre scale/ruler. Proportion can be defined as a ratio of two different values. These values are traditionally h/d for a letter [3]. This step is performed in two distinct sub-steps. Sub-step 1 in step 2, is for samples in *Set P*. 20 locations were marked in P1', P1'' and P1'''. These locations were supposed to be words in the document made of characters having both an *"h"* and a *"d"* to them. 20 values were first collected from 20 locations in P_1'. The values of *"h"* and *"d"* were measured with respect to the baseline at each location. *h/d* yielded the value of L at location *1*. These values were denoted as $\{L'_1, L'_2, L'_3,\ldots,L'_{20}\}$. A median was calculated. This is called A'_1. Similarly,the most recurring values fromP_1'' and P_1''' were also obtained. These were A''_1 and A'''_1. These 3 values were averaged for a final value of proportion for Subject *1*. This is referred to as A_1. Similarly, an array was generated with all average values of proportion for each sample such that, A $=\{A_1,A_2,A_3,\ldots,A_{20}\}$. These are presented in Table 2.

It is important to be noted here, that separate value arrays for each sample were generated for Set P. A combined value for average was then calculated. This was done so the proportion maintained by the author in the present times can be calculated accurately. It is also interesting to note here that in cases of all subjects, except subject *11*, the values of A'_n, A''_n and A'''_n were exactly the same. This proves the literature stating proportion to be an individual characteristic, mathematically. The process is depicted in Figure 3.

Sub-step two of Step two, is repeating measurements for all documents in Set *O*. Set *O* has just one sample each belonging to every subject. For sample O_1, twenty distinct locations are marked in the document. Each location needs to necessarily possess both *"h"* and *"d"* components to the characters in the word. Each location produces a value of proportion. These are denoted as $\{M_{11}, M_{12}, M_{13},\ldots, M_{120}\}$. Averaging M_1 to M_{20} gives us the average value of proportion B_1, for Subject *1* in a document written by him/her 10-15 years ago. Similarly, values of proportion are collected for all samples in Set *O*. This gives a value array of $B=\{B_1,B_2,B_3,\ldots,B_{20}\}$.

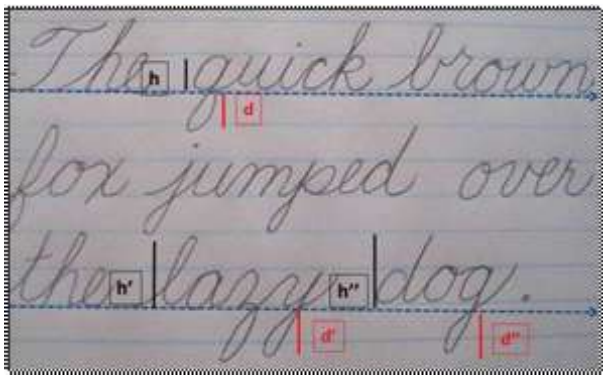


Fig. 3: Various *"h"* and *"d"* values are calculated wrt baseline at several locations in each document

Step three is calculation of hiatus or inter-word spacing. Measurements are done using a conventional sub-millimetre ruler. Calculations are performed with respect to the baseline. Hiatus between two words, as per definition, is the space between the end of the exit stroke of the last character of the first word and the starting stroke of the first character of the second word. These locations can be marked in a document. These are

depicted below in Figure 4.

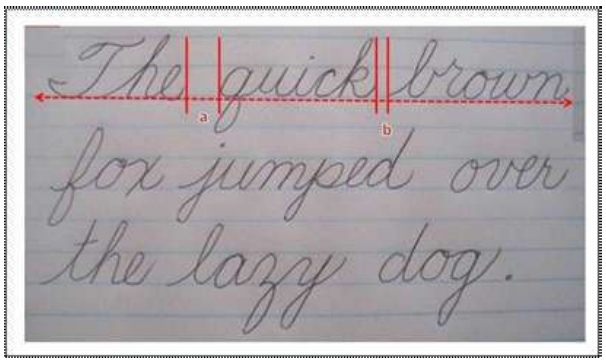


Fig. 4: *'a'* and *'b'* indicate hiatus between words

'a' and 'b' indicate inter-word spaces found between words at various locations. This value can be measured at several random locations inside a document. When averaged they can reveal the average hiatus maintained by an author during writing. This is constant for every individual [ref] enabling it to be considered as an individual characteristic. This was established using samples in *Set P*, as was done in Step 2. Average hiatus values obtained from samples in *Set P* are maintained in an array called K such that, $X = \{X_1, X_2, X_3 \ldots, X_{20}\}$. These were compared to average of hiatus found for authors in *Set O*. They were stored in a value array called Y such that $Y = \{Y_1, Y_2, \ldots, Y_{20}\}$.

Calculations and Observations

Detailed value charts have been made available for public viewing on:

(url: https://drive.google.com/open?id=1ioqoa-73en_INGBoNDRq6g8bWOBjyd9k)

Final averaged value charts are given in Table 2 and Table 3, for both individual characteristics separately.

This paper calculates the percentage change of an individual characteristic over a span of 15 years. Post calculation, it aims to decipher a pattern, if any amongst individuals and the percentage change.

For Proportion

Table 2 depicts values of arrays A and B. (B-A) is represented as dC or change in value of proportion in the time span of 10-15 years. The below equation will give the percentage change in value of proportion over time

$$C_n = \frac{(dC_n)}{B_n} \times 100$$

For Hiatus

Table 3 depicts values of array X and Y. (*Y*-*X*) is represented as dH or change in value of hiatus in the time span of 10-15 years. The below equation will give the percentage change in value of hiatus over time.

$$\%H_n = \frac{(dH_n)}{Y_n} \times 100$$

Table 2: Averaged values of Proportions for all subjects

For Proportion		
from Set P	**from Set O**	**Delta**
1.45	2.1	0.65
1.3	1.9	0.6
1.3	1.9	0.6
1.3	2	0.7
1.3	1.9	0.6
1.2	1.7	0.5
1.6	1.2	-0.4
1.5	1.5	0
1.5	2.1	0.6
1.2	1.7	0.5
1.1	1.7	0.6
1.7	2.6	0.9
1.3	2	0.7
1.5	2.1	0.6
0.9	1.4	0.5
1	1.8	0.8
1.5	2.2	0.7
1	1.1	0.1
1	1.47	0.47
1.1	1.67	0.57

Table 3: Averaged values of Hiatus for all subjects

for Hiatus (in cms)		
from Set P	**from Set O**	**Delta**
0.75	0.94	0.19
0.89	1.1	0.21
0.56	0.56	0
1.05	1.31	0.26
0.86	1.06	0.2
0.6	0.74	0.14
0.61	0.61	0
1.3	1.6	0.3
0.73	0.91	0.18
0.72	0.89	0.17
0.93	1.17	0.24
0.82	1.01	0.19
0.66	0.82	0.16
0.74	0.92	0.18
0.68	0.84	0.16

0.83	1.03	0.2
0.91	1.12	0.21
0.5	0.62	0.12
1.1	0.82	-0.28
0.4	0.5	0.1

Table 4 depicts values of %C and %H for all 20 subjects, corrected to two decimal places.

Table 4: PercentageChange in Individual Characteristics

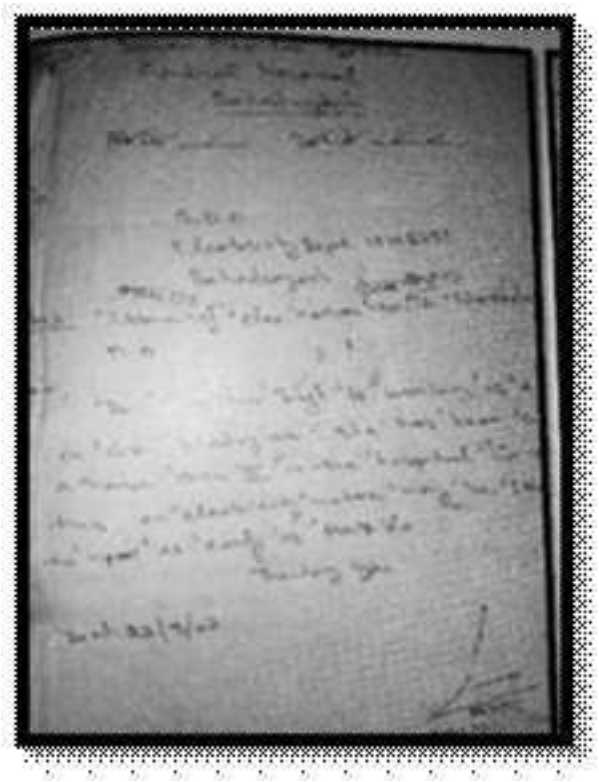
	% change	
Subject no.	**%C**	**%H**
1	44.83	25.33
2	46.15	23.60
3	46.15	0.00
4	53.85	24.76
5	46.15	23.26
6	41.67	23.33
7	-25.00	0.00
8	0.00	23.08
9	40.00	24.66
10	41.67	23.61
11	54.55	25.81
12	52.94	23.17
13	53.85	24.24
14	40.00	24.32
15	55.56	23.53
16	80.00	24.10
17	46.67	23.08
18	10.00	24.00
19	47.00	-25.45
20	51.82	25.00

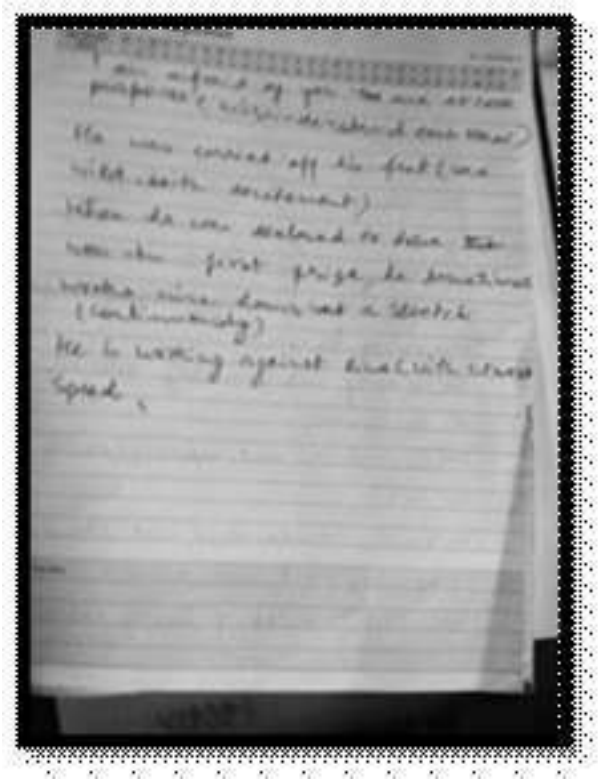
It is brilliant to observe here, that the trend in percentage change in both individual characteristics is similar throughout the sample population. For proportion, it may be observed, that the ratio of sizes of handwriting for almost all 20 individuals changes by 40-50% in a span of 15 years. There are exceptions observed with subjects8, 16 and 18. For hiatus, it is observed that for all members of the test set, the value of spacing increase from 20-25% in a matter of 15 years. There is an exception for subject number 7.

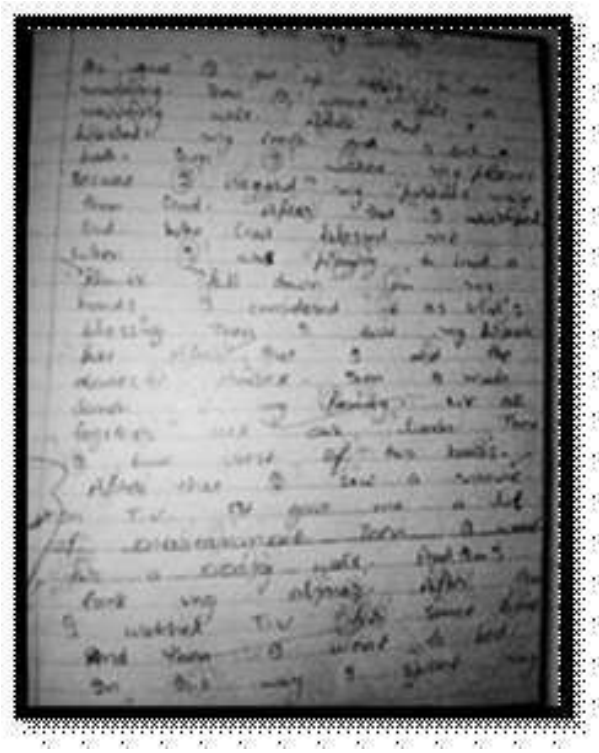
Conclusion

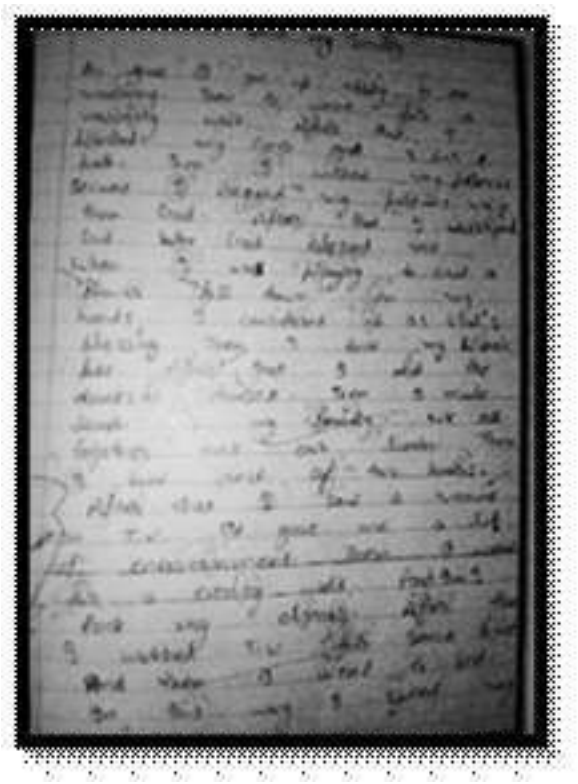
Such a numerical approach to studying individual characteristics is novel. The quantitation of individual characteristics to objective, reproducible numerical values is also a unique feature of this study. It opens doors for quantification of individual characteristics which in turn leads to primary steps for an automated approach to handwriting analysis. The results obtained, are very encouraging. They clearly indicate a pattern followed by the population. The further derivations of the obtained results could be several. The percentage change observed could be a function of the time-elapsed. This could be done if the study is continued on the same sample population and more samples are collected after 10 more years. The percentage change observed could also be a function of the physical attributes of a subject. Nonetheless, this study opens up several doors for further research and more patterns and dependencies to be discovered.

Based on the study performed and the results received, we may be able to conclude that hiatus and proportion is found toincrease bysimilar factors in a span of 15 years, in the handwriting of populations. A few of the original samples used for the study are given below, aggregated as Figure 5.









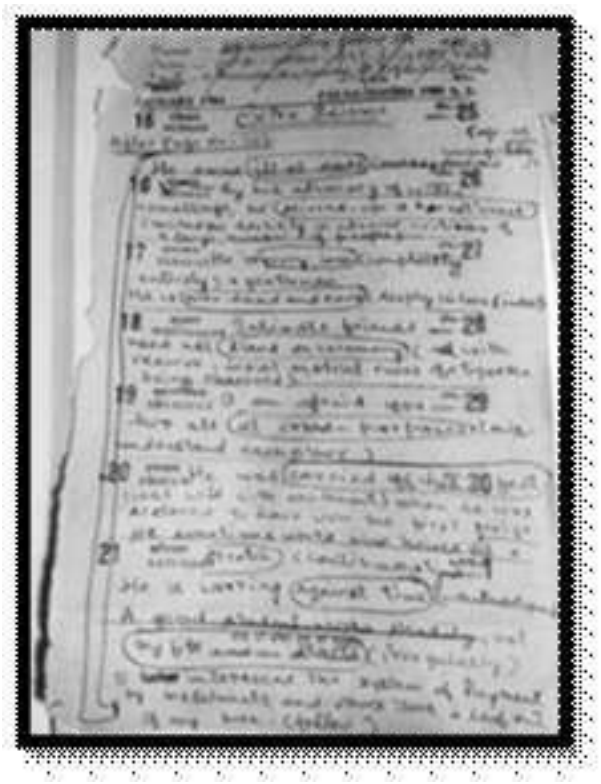


Fig. 5: A few examples from Set P and Set O

Extensive sampling could clarify population trends. Sampling in fixed age groups could clarify trends in percentage change, and so on. Accurate computerized measurements could give a more accurate understanding.

References

1. Osborn Albert S. Questioned Document Problems, The Discovery and Proof of the Facts. Montclair, N.J. : Patterson Smith, 1991.p.c1944
2. Huber Roy A, Headrick AM. Handwriting Identification: Facts and Fundamentals. New York: CRC Press. 1999.
3. Montgomery Ivonne. Minnesota Handwriting Assessment Overview/Evidence for Practice (E4P). 2004, 10.13140/RG.2.2.12583.04003
4. Barry J. Graphology Is Serious Business in France : You Are What You Write? 1993, New York Times; Retrieved 18 September 2010; Accessed 16 April 2018
5. McAllister CN. Research: A movement used in handwriting. Yale Psychological Laboratory, 1900;8: 21–63.
6. https://www.canyonranch.com/blog/health/how-your-brain-changes-with-age; accessed April 16, 2018.
7. Hilton O. Influence of Age and Illness on Handwriting Identification Problems; Journal of Forensic Science. 1977;9:161-72
8. Longstaff MG & Heath RA. The influence of tremor on handwriting performance under conditions of low and intermediate physical stress; Journal of Forensic Document Examination. 2000;13:25-44.
9. Dixon A, Kurzman R, Friesen, Ingrid. Handwriting Performance in Younger and Older Adults: Age, Familiarity, and Practice Effects. Psychology and Aging. 1993;8(3):360-70.
10. Baggett B. Handwriting Analysis: Quick Reference Guide. Empresse Publishing, Dallas, Texas. 2004.
11. Harrison WR. Suspect Documents: Their Scientific Examination. NY: Fredrick A. Praeger. 1958.