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Original article

The Comparative Influence of Culture and Schooling Environment on Handwriting Features

التأثير المقارن للثقافة والبيئة المدرسية على ملامح الكتابة اليدوية

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Abstract

Handwriting is an acquired trait of an individual which is primarily culture and environment dependent. The present study attempts to assess the relative influence of schooling environment and culture upon handwriting features. The paper sets forth the computational and conventional analysis of handwriting samples obtained from two cultural/ethnic groups in India living in the same and different geographical regions. Striking significant differences were observed in key handwriting features between writers of the same cultures who were living in different regions and attended different school settings. Contrary to this, handwriting features were insignificant between writers of different cultures living in the same region at the same school.

Keywords: *Forensic Sciences, Environment, Culture, Handwriting Features, Conventional, Computational.*

المستخلص

الكتابة اليدوية هي سمة مكتسبة للشخص وتعتمد في المقام الأول على الثقافة التي تربى عليها والبيئة التي نشأ فيها. تحاول هذه الدراسة تقييم التأثير النسبي للبيئة المدرسية والثقافة على ملامح الكتابة اليدوية. وقد اعتمدت الورقة على التحليل الحاسوبي والتقليدي لعينات الكتابة اليدوية التي تم الحصول عليها من مجموعتين ثقافيتين / إثنيتين مختلفتين في الهند وتعيشان في مناطق جغرافية واحدة أو مناطق جغرافية مختلفة. وقد لوحظت اختلافات كبيرة ذات دلالة في ملامح الكتابة اليدوية الرئيسية بين الكُتّاب من الثقافات نفسها الذين كانوا يعيشون في مناطق مختلفة وحضروا إعدادات مدرسة مختلفة. وخلافا لذلك، فإن ملامح الكتابة اليدوية لم تظهر اختلافات ذات دلالة بين الكتاب من مختلف الثقافات الذين يعيشون في نفس المنطقة ويتشاركون نفس المدرسة.

الكلمات المفتاحية: علوم الأدلة الجنائية، البيئة، الثقافة، ملامح الكتابة اليدوية، التحليل التقليدي والحاسوبي.

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1. Introduction

Handwriting is a behavioural skill of humans which is acquired after birth. Learning the ability to write is considered as one of the most complicated and advanced skills of human behaviour. The particular way in which an individual learns these skills is primarily a function of the culture and schooling environment in which he or she is reared and matured. Handwriting, being a neuromuscular activity, relates the cognitive aspects of the brain with muscular movements. Culture and schooling environment play a crucial role in influencing the cognitive and motor development of a child, and this development varies greatly in different cultural and school settings.

The nature or appearance of handwriting is primarily environment, experience and culture dependent [1]. A writer's cultural and schooling environment is considered as a matrix from which the skill of handwriting is acquired or cultivated. The development of handwriting passes through different stages in the lifetime of a writer. During the initial stage, a writer develops writing skills and learns the basic letter formations by replicating, copying and imitating the letter designs formed by his family members. After mastering the basic writing skills, the writer tries to imitate other's handwriting and simultaneously imbibes more individuality into his writing. Up to this stage, a writer remains under the influence of his cultural peers, relatives and teachers which leads to the transmission of graphical skills vertically, horizontally and obliquely in a group. In the latter stages, previously developed handwriting characteristics become more habitual and changes occur, only in fluency or design under the influence of writing frequency and a particular occupation.

1.1 Cultural Factors Influencing Handwriting

According to Tylor [2] "culture is that complex whole which includes knowledge, belief, art, morals, law, custom, and any other capabilities and habits acquired by an individual as a member of the society". An ethnic or population group consists of descendants and ancestors, where cultural transmission occurs in the form of customs, rituals and preconceptions. Handwriting is also considered a skill which is initially acquired from parents and cultural peers who assist their children in teaching pre-writing skills, holding writing instruments, sitting in an upright posture, developing hand-eye coordination, tracing the alphabets and motivating the consistent formation of letters. Additionally, teaching the motor preliminaries of handwriting involves the introduction of cultural standards such as regularity and neatness, the introduction of cultural biases such as slant, counter clockwise rotations, and left to right transport. It also involves the introduction of various constraints such as posture, grasp, and which hand is being used. In different cultures and societies these standards, biases, and constraints may differ, producing different effects in the writing of their subjects. Additionally, parents or cultural peers assist their children in teaching pre-writing skills, holding writing instruments, sitting in upright posture, developing hand-eye coordination, tracing the alphabets and motivating the consistent formation of letters [1, 3].

1.2 Schooling Environmental Factors Influencing Handwriting

Schooling environment refers to the institutional setting of a school which provides a learning environment for the students under the direction of a teacher or instructor. Much of an individual's handwriting is dictated by the teaching systems and writing styles prevalent in a particular geo-

graphical location [4]. There are noticeable differences between the individual teaching systems in different regions [5]. Additionally, the physical settings in which a child is reared also play an important role in the development of the motor aspect of handwriting. Children who attend the private pre-school type-setting, having plenty of open space to play, gymnasia, courts and playgrounds display higher motor activities than children who participated in public preschool centres that have limited spaces for sports and free play and do not include any physical education lessons into their schedule.

The present study aims at comparing the handwriting features of the writers belonging to:

(a) Same cultural/ethnic group living in different geographical regions and studying in different schools

(b) Different cultural/ethnic groups living in the same geographical region and studying in the same school.

(c) Different cultural/ethnic groups living in different geographical region and studying in different schools.

2. Materials and Methods

A source document, which was used as a standard for copying the text, was designed for the present study. The source document consisted of all letters and certain character combinations of interest. It also contained a general document structure that allowed the extraction of macro-features of handwriting such as slant, margin, orientation and skewness. Each writer was provided with a plain sheet and blue ball pen of the same brand. Writers were requested to copy out the source document in their most natural handwriting. In addition, writers were also asked to fill in a proforma that encoded general information like name, age, sex, ethnic/population group and area/geographical region [3].

2.1 Writer Population

A total of 260 English handwriting samples were obtained from writers of Brahmin and other ethnic groups in the Nagpur and Delhi regions. The handwriting samples were gathered from R.D. Rajpal school of Delhi and Dinanath Senior Secondary College of Nagpur. R.D. Rajpal School is one of the modernized private schools of Delhi while Dinanath Senior Secondary College is run by a trust. The educational level of writers ranged from 10th to 12th standard, and the age of writers varied between 16-20 years. Table-1 shows the distribution of writers according to ethnic groups.

In different states of India, scheduled castes are known by different names. For the present study Chambhars of Nagpur and Chamars of Delhi were referred to as scheduled caste.

The current study compares the handwriting features of:

Table 1- *Distribution of writers according to cultural groups.*

S. No.	Region	Cultural Groups		Total
		Brahmins	Scheduled Castes	
1	Nagpur	72	60	132
2	Delhi	71	57	128
	Total	143	117	260

(1) (a) Writers of the Brahmin ethnic group studying in R. D. Rajpal school of Delhi and Dinanath Senior Secondary College of Nagpur and (b) Writers of the Chambhar ethnic group in Nagpur and the Chamar group in Delhi studying in R. D. Rajpal school of Delhi and Dinanath Senior Secondary College of Nagpur.

(2) (a) Writers of the Brahmin and Chambhar and Chamar groups studying in R. D. Rajpal school of Delhi (b) Writers of the Brahmin, Chambhar and Chamar groups studying in Dinanath Senior Secondary College of Nagpur.

(3) (a) Writers of the Brahmin culture group studying in R. D. Rajpal school of Delhi and writers of the Chambhar and Chamar groups studying in Dinanath Senior Secondary College of Nagpur. (b) Writers of the Brahmin group studying in Dinanath Senior Secondary College of Nagpur and writers of the Chambhar and Chamar groups studying in R. D. Rajpal school of Delhi.

After data collection, each of the handwriting samples was processed. The processing stage was further segmented into two stages: Pre-Processing stage and Handwriting Feature Extraction stage.

2.2 Pre-Processing of Handwriting Samples

Pre-processing is a common name for operations with images at the lowest level of abstraction. The aim of pre-processing is an improvement of the image data that supresses unwilling distortions or enhances some image features important for further processing [6]. This stage consists of scanning, binarization, noise removal and segmentation.

The obtained handwriting samples were scanned at 300 dpi resolution and converted into a scanned digital image using a HP LaserJet M1136 MFP scanner. After scanning all the handwritten samples, binarization was performed. Binarization is a process which divides the pixel values of a digital image into two groups: white as background pixel and black as foreground or object pixel. It reduces the storage requirements and increases the speed of data processing.

During the third step of pre-processing, noise removal was done by using median filters. These filters work by moving through images pixel by pixel and replacing each pixel value of the image with median value of neighbouring pixels. After the denoising step, the handwritten text was segmented into lines; each line into words and then each word was segmented into constituent letters or alphabets to get the characters or character combinations of interest [Figure-1 & 2].

2.3 Feature Extraction

After pre-processing the handwriting samples, handwriting features were extracted for further processing. For the present study, both conventional and computational handwriting features were taken into account. Conventional features are manually analysed and are commonly used by forensic document examiners to determine the authenticity or authorship of a disputed document, whereas computational features are computed algorithmically with the help of computer software. The present study included sixteen handwriting features (eleven computational and five conventional) in total which consisted of pen pressure, handwriting style, slant, height, alignment, pattern of left and upper margin, aspect ratio of bigram 'th', height relation of 't' to 'h' in 'th' bigram, presence of loop in 't' and 'h' in bigram 'th' and pattern matching of 'y', 'm', 'd', 'f' and 't' character. A brief introduction of the extracted features is given below:

1. Pen Pressure: This is the amount of pressure used to push the pen across the paper. The amount of pen pressure

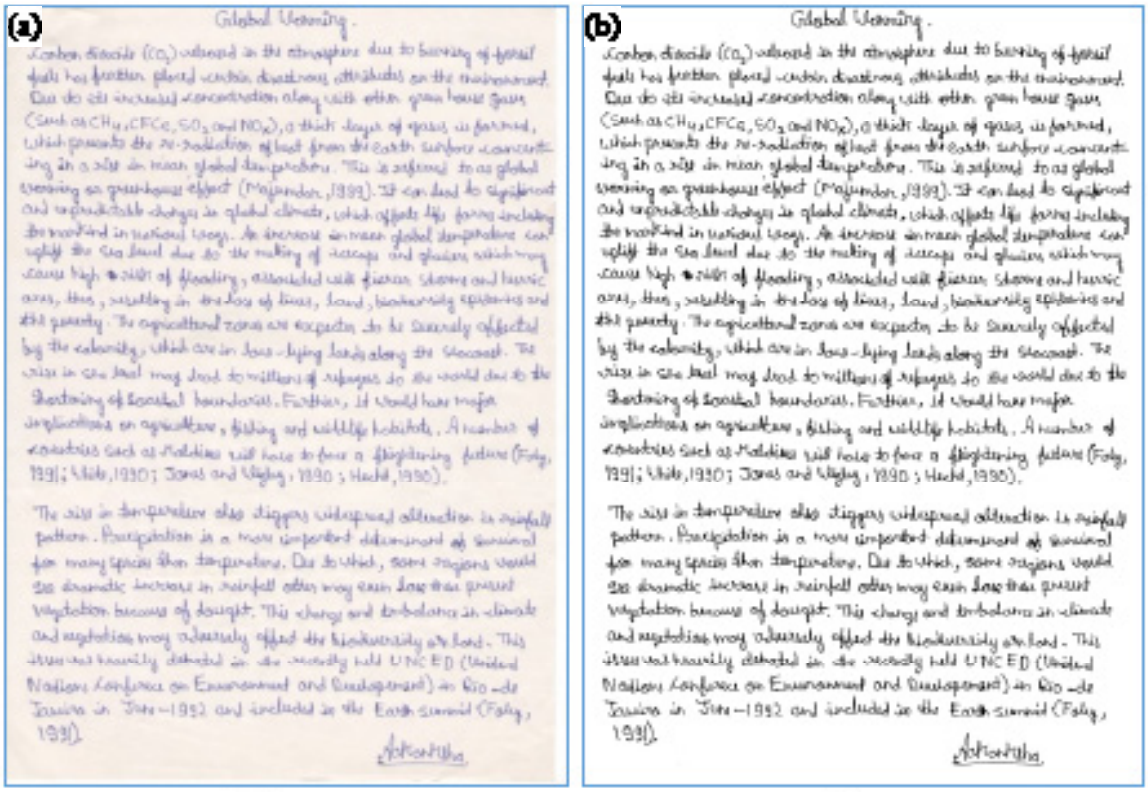

Figure 1- *(a) Digitally scanned handwriting sample (b) Binarized handwriting sample.*

varies for different writers from light to heavy [7]. For the present study, pen pressure was computed using grey level threshold algorithm in MATLAB software. The grey level threshold algorithm maps the grey-level pixel values in the image that are below a particular threshold to pure black (foreground) and those above the threshold to pure white (background). The value of the threshold (the grey-scale value that partitions the foreground and background of the grey-level image) is indicative of the pen-pressure, with higher values indicating lighter pressure [8].

2. Handwriting Style: Style is a term that has been applied rather loosely to apparently different patterns of writing habits executed by individuals under different writing circumstances. There are three principle styles or categories into which handwriting may be segregated: cursive writing, hand lettering and manuscript writing. In the present study, Handwriting style was computed by analysing the number of connected components. A connected component is a maximal region of connected pixels. The binary handwritten images were further processed to measure the connected components. The boundary or contour of each connected component were stored and manipulated. The average number of connected components can be used as a measure of writing connectivity. Examples of connected components for three handwritten samples are shown in Figure-3.

3. Slant: Accroding to Hilton [1], slant is the angle or inclination of the axes of letters relative to the baseline. The direction of slant depends upon the preferences of the writer, the naturalness of his writing, and is influenced by the position of the writer‘s arm, the style of holding the pen and the angle of the paper. In the present study, the slant of the handwriting is computed by measuring the angle of the letters with the baseline, the ginput command (MAT-

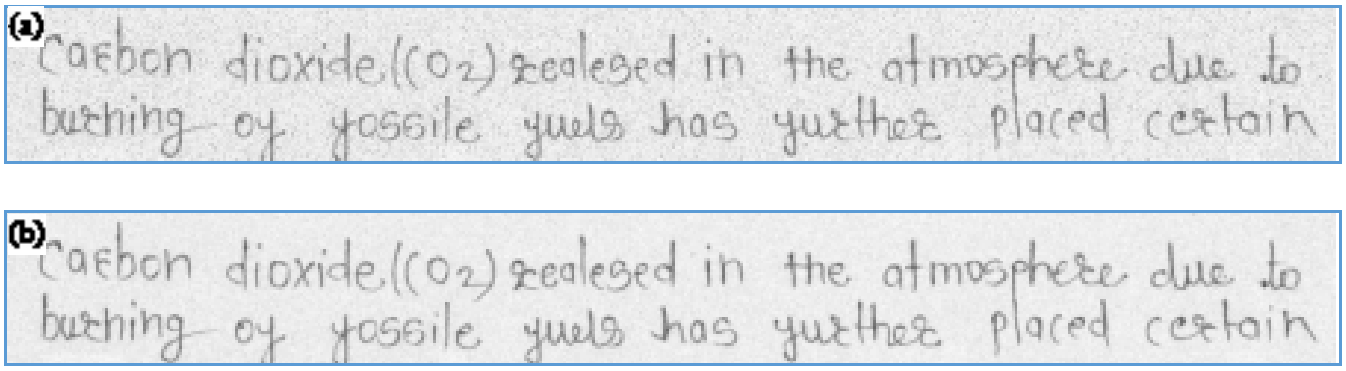

Figure 2- *An example of noise removal step (a) Noise produced in handwriting sample due to scanning (b) Handwriting sample after de-noising.*

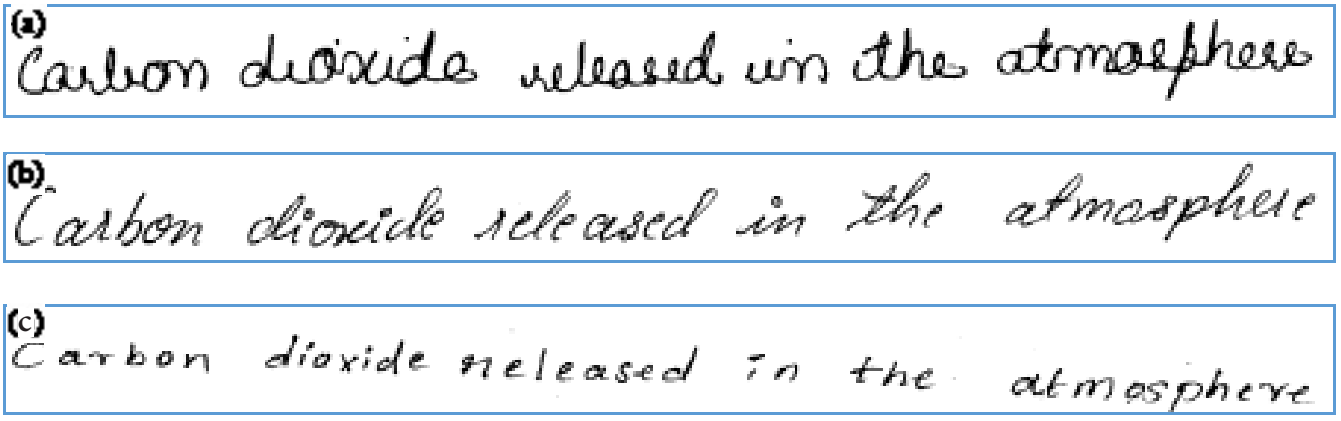

Figure 3- *Number of connected components in (a) 9 (b) 28 & (c) 47.*

LAB) stores the value of respective x and y coordinates as a matrix in a defined variable A and B, the elements of the matrix for different x and y coordinates were computed to get the angle of slant [9]. It measures the inverse tangent angle using the following equation:

$$\tan \theta = y_2\text{-}y_1 / x_2\text{-}x_1$$

The overall slant of writing was taken as the average of all angles of all the line elements i.e. letters and numerals with vertical shaft e.g. B, D, E, F, H, I, 1, 4 etc.

4. Height of Handwriting: According to Huber and Headrick [1], height of the handwriting is based on the measurements or judgement of vertical dimensions of letters, presuming that there is sufficient consistency to permit a reasonable approximation to be determined. In the present study, the average height or vertical dimension of the handwriting was obtained from the capital or block letters written in the handwriting sample. The height of the handwriting was computed using image processing toolbox of the Image J Software. Image J is a java based image processing software developed at the National Institute of Health. It was calculated by measuring the distance (in pixels) between the maximum and minimum point of the vertical dimension of the capital letters. It was then averaged over the entire document.

5. Alignment: Alignment refers to the relation of successive letters of a word, signature, or line of writing to an actual or imaginary baseline (imaginary line on which writing is aligned). The majority of people exhibit an as-

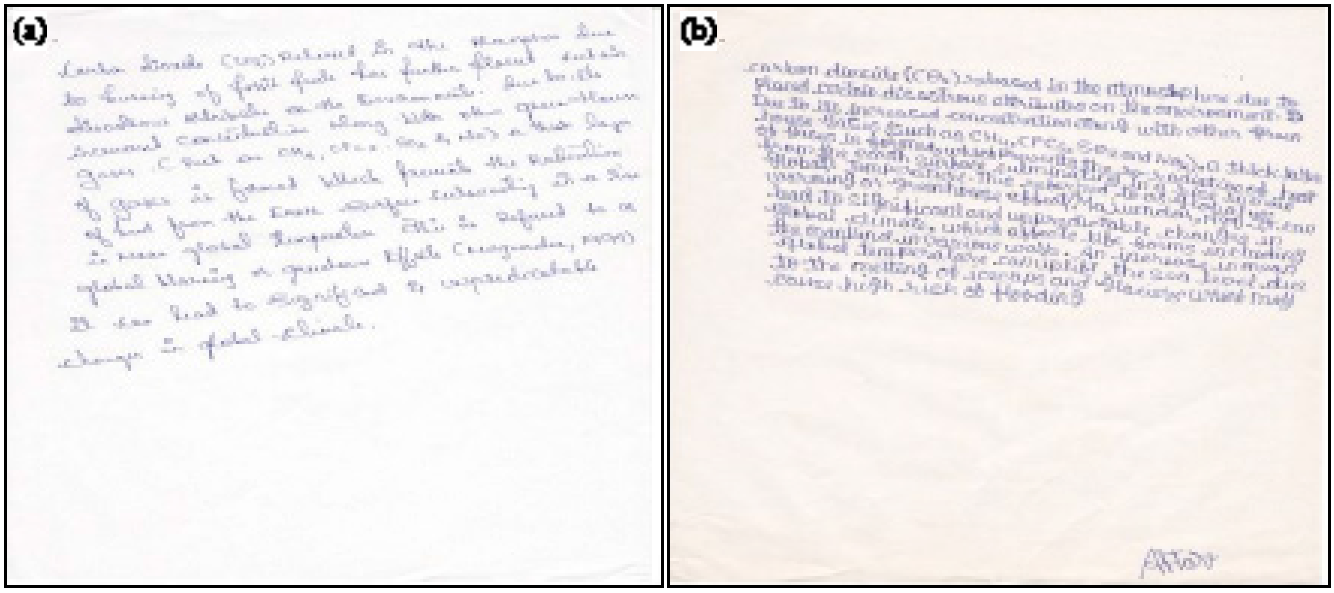

Figure 4- *Types of alignment (a) Ascending and (b) Descending.*

cending (i.e. rising) baseline in their writing. Some maintain a horizontal baseline while the baseline of others tends to descend. In this study, alignment of the handwriting was classified as ascending and descending which was visually observed. Examples of ascending and descending alignments are shown in Figure-4.

6. Margin: Margin is the top, bottom and side spaces on the page which frames the body of written, typed or printed matter (Dictionary of Handwriting Analysis Terms). Writers are instructed to arrange their writing on a page by leaving margins all around the writing area. It is common for left margins to be pronounced and consistent and for right margins to be completely disregarded. Indeed, all four margins may exhibit different dimensions [1]. For the present study, different patterns of left and upper margins were examined to study variations in the handwriting patterns of regional population groups in India.

7. Aspect Ratio of Bigram 'th': The aspect ratio describes the proportional relationship between the height and width of an image. Different systems of writing vary in the proportion of height to width of the letters [10]. A bigram is a sequence of two consecutively written units or elements such as letters, syllables or words. The 'th' bigram is the most frequently occurring letter pair which has been studied by questioned document examiners [11] and accounts for around 4% of all two-character combinations [12]. In addition, the discriminative power of the 'th' bigram (grapheme) is higher than that of single characters [13, 14]. A minimum bounding rectangular box enclosing 'th' bigram was created by manual cropping. The height and width of the 'th' bigram was computed (in pixels) in the image processing toolbox of the image j software. The aspect ratio of bigram 'th' was calculated in the SPSS software.

8. Height Relation of 't' to 'h' in Bigram 'th': The relative height of one letter to the other letter is an individual characteristic of handwriting. Relative height is the relationship of the measures, along separate axes, of the vertical dimensions (only) of two or more discrete entities or components to each other [1]. The heights of letter 't' and 'h' in the 'th' bigram were measured by the distance

(in pixels) from the baseline to the apex of the letter 't' or 'h' [Figure -5].

9-10. Presence or Loop in 't' and 'h' in Bigram 'th': A loop is a handwritten pattern made of several strokes formed when the writing instrument returns to a previous location while touching the writing surface continuously, giving a closed outline with a 'hole' in the centre [15]. They are also considered to be good features to distinguish writers [12]. For the present study, presence or absence of loop in 't' and 'h' character in bigram 'th' was observed manually.

11-16. Pattern Matching of Lower Case 'y', 'm', 'd', 'f' and 't': The method of formation or construction of individual letters can be used as an important discriminating element of handwriting. The designs, shapes and size of the cursive letters exhibit much wider variations than other features of handwriting. In the present study, variations in handwriting with respect to letter formation were studied using template matching algorithm based on normalized cross-correlation. The patterns of lower case alphabet 'y', 'm', 'd', 'f' and 't' have been chosen to find out the variations in handwriting. Template matching technique is used in digital image processing to find out the areas of an image that are similar to a pre-defined template image. Normalized cross-correlation (NCC) has been commonly used as a metric to evaluate the degree of similarity (or dissimilarity) between two compared images [16].

The Null Hypothesis held that there would be no overall difference in sixteen handwriting features stated above between writers of the same ethnic group who were living in different geographical regions and between writers of different groups living in same geographical region and sharing same school. Therefore, if the null hypotheses are true:

Pbn = Pbd and Pscn =Pscd

Pbn= Pscn and Pbd=Pscd

where *P* is the probability of observing a handwriting feature in the handwriting of the particular cultural/ethnic and regional group, bn = Brahmin group of Nagpur; bd = Brahmin group of Delhi; scn = Chambhar and Chamar groups of Nagpur and scd = Chambhar and Chamar groups

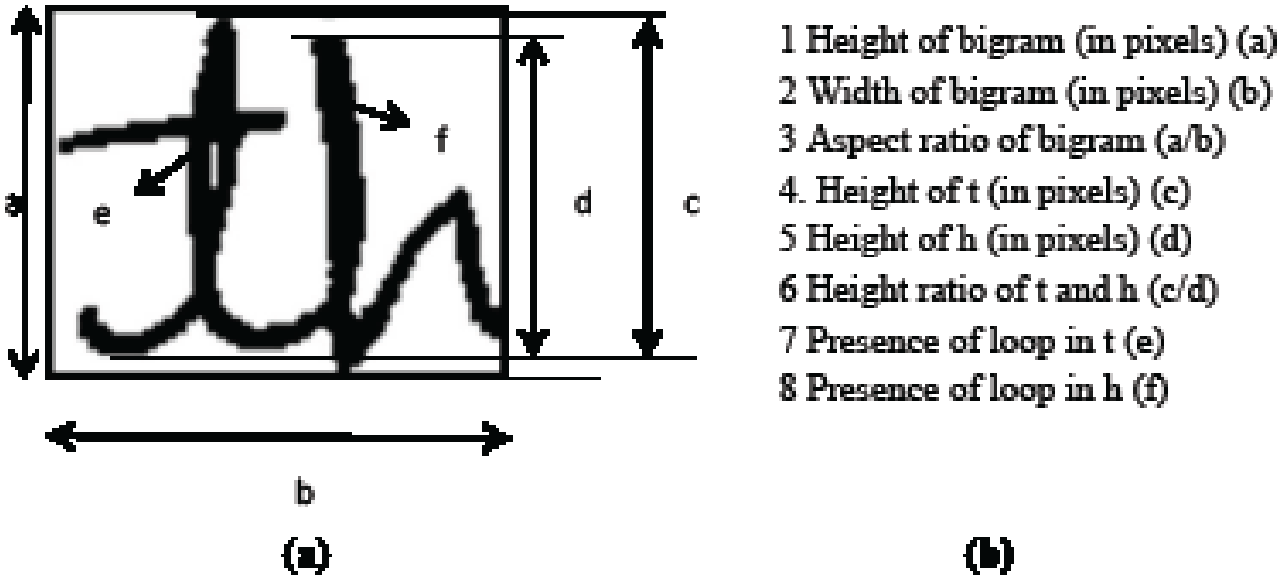

Figure 5- *(a) Bigram 'th' (b) Extracted features.*

of Delhi

The Alternate Hypothesis would then be:

Pbn ≠ Pbd and Pscn ≠ Pscd

Pbn ≠ Pscn and Pbd ≠ Pscd

3. Results and Discussion

After processing handwriting samples, values of extracted features were submitted to student's t-test (for quantitative and computational features) and chi-square test (for qualitative and conventional features) to check statistically for the difference between writers of the same cultural group living in different geographical regions and studying in different school settings (Table-2, 3) and writers of different cultural groups living and studying in the same geographical region and schooling environment (Table-4, 5). In order to present the comparison of handwriting features of writers of different cultural groups living and studying in different geographical regions and schooling environments, t-test and chi-square test were performed (Table-6, 7).

It was observed (Table-2, 3) that writers of same cultural/ethnic group who were living in different regions and studying in different schools manifested significant differences in the majority of handwriting features, while writers who belonged to different cultural/ethnic groups sharing the same region and schooling (Table-4, 5) showed no significant differences in any of the extracted handwriting features. Brahmin writers of Nagpur and Delhi region showed significant differences in pen pressure, alignment, pattern of left and upper margin, aspect ratio of bigram 'th', presence of loop in 't' in bigram 'th' and pattern matching of 'y', 'd', 'f' and 't' characters. With respect to Chambhar and Chamar writers of Nagpur and Delhi regions, significant differences were found in pen pressure, height of handwriting, alignment, pattern of left margin, aspect ratio of bigram 'th' and pattern matching of 'y', 'd' and 't' characters.

The observed significant differences between writers of same cultural/ethnic groups living in different geographical regions and attending different schools could be because of the differences in the individual teaching system and writing styles prevalent in a particular region. There are numerable differences in teaching systems in different regions, including the differences in the make-up of characters, the structure of the language, the way handwriting is taught at school and the importance placed upon it. The differences between teaching systems are hard to generalize due to the differences in teaching style at individual schools [5]. According to Feingold [17], "Public schools in Delhi lay no emphasis on teaching cursive as correct print writing and accurate use of English is what matters most. Print writing helps children relate what they read in their textbooks to what the teacher writes on the blackboard." Contrary to it, schools in Nagpur teach students to write in cursive handwriting style and encourage them to use scientific techniques to improve their handwriting [18]. Additionally, the strong regional variation between Nagpur and Delhi in writing English could also be one of the probable reasons behind the significant differences.

Whilst this study highlighted several significant differences between the handwriting features of writers of same cultural groups who were living in different regions and attending different schools, it was also found that writers of different cultures who were sharing the same geographical region and school settings have no significant differences in their handwriting features. In the present study, writers of Brahmin and Chambhar and Chamar cultural/ethnic

Table 2- *Comparison of computational (quantitative) handwriting features between writers of same cultural group living in different geographical regions (attending different schools).*

S. No.	Handwriting Features	Brahmins		t-value	Scheduled Castes		t-value
		Nagpur	Delhi		Nagpur	Delhi	
		Mean±S.D.	Mean±S.D.		Mean±S.D.	Mean±S.D.	
1	Pen Pressure	0.72±0.024	0.74±0.019	-7.571***	0.72±0.030	0.75±0.021	-6.674***
2	Handwriting Style (number of connected components)	24.53±9.682	23.87±8.959	0.419	21.78±9.462	24.64±9.591	-1.1616
3	Slant	84.23±12.662	85.17±12.078	-0.455	87.69±10.955	86.00±12.511	0.776
4	Height of Handwriting	70.47±13.230	70.62±21.361	-0.052	72.34±13.542	67.14±15.408	1.932*
5	Aspect Ratio of Bigram 'th'	0.87±0.250	0.77±0.213	2.609**	0.95±0.263	0.72±0.188	5.372***
6	Height Relation of 't' to 'h'	1.08±0.227	1.08±0.177	-0.142	1.08±0.212	1.12±0.204	-1.034
7	Pattern Matching of 'y' template	0.47±0.089	0.44±0.085	1.939*	0.48±0.102	0.43±0.093	2.427**
8	Pattern Matching of 'm' template	0.39±0.069	0.37±0.068	1.527	0.40±0.054	0.38±0.073	1.645
9	Pattern Matching of 'd' template	0.50±0.085	0.47±0.078	2.367**	0.50±0.075	0.47±0.075	2.151*
10	Pattern Matching of 'f' template	0.49±0.116	0.44±0.101	2.710***	0.48±0.100	0.44±0.089	2.222
11	Pattern Matching of 't' template	0.48±0.085	0.46±0.088	1.924*	0.49±0.082	0.46±0.069	2.094*

$p^* < 0.05$, $p^{**} < 0.01$, $p^{***} < 0.001$

Table 3- *Comparison of conventional (qualitative) handwriting features between writers of same cultural group living in different geographical regions (attending different schools).*

S. No.	Handwriting Features	Categories of Features	Brahmins			Scheduled Castes		
			Nagpur	Delhi	Chi-Square	Nagpur	Delhi	Chi-Square
			n(%)	n(%)		n(%)	n(%)	
12	Alignment	Ascending	57(79.2)	38(54.3)	9.923**	47(78.3)	60.7	4.268*
		Descending	15(20.8)	32(45.7)		13(21.7)	39.3	
13	Presence of loop in 't' in bigram 'th'	Yes	15(20.8)	5(7.0)	5.652**	14(23.3)	7(12.5)	2.293
		No	57(79.2)	66(93.0)		46(76.7)	49(87.5)	
14	Presence of loop in 'h' bigram 'th'	Yes	9(12.5)	9(12.7)	0.001	11(18.3)	7(12.5)	0.752
		No	63(87.5)	62(87.3)		4(6.7)	5(8.9)	
15	Pattern of Left Margin	Wide Left	3(4.2)	14(19.7)	22.505***	27(45.0)	31(55.4)	9.689*
		Narrow Left	35(48.6)	29(40.8)		16(26.7)	3(5.4)	
		No Left	21(29.2)	4(5.6)		13(21.7)	18(30.4)	
		Normal Left	13(18.1)	24(33.8)		3(4.2)	14(19.7)	
16	Pattern of Upper Margin	Wide Upper	3(4.2)	17(23.9)	11.803**	6(10.0)	11(19.6)	2.214
		Narrow Upper	29(40.3)	21(29.6)		17(28.3)	15(26.8)	
		No Upper	37(51.4)	31(43.7)		1(1.7)	1(1.8)	
		Normal Upper	3(4.2)	2(2.8)		36(60.0)	29(51.8)	

$p^* < 0.05$, $p^{**} < 0.01$, $p^{***} < 0.001$

Table 4- *Comparison of computational (quantitative) handwriting features between writers of different cultural groups living in same geographical region (attending same school).*

S. No.	Handwriting Features	Nagpur			Delhi		
		Brahmins	Scheduled Castes	t-value	Brahmins	Scheduled Castes	t-value
		Mean±S.D.	Mean±S.D.		Mean±S.D.	Mean±S.D.	
1	Pen Pressure	0.72±0.024	0.72±0.030	-0.022	0.74±0.019	0.75±0.021	-1.204
2	Handwriting Style (number of connected components)	24.53±9.682	21.78±9.462	1.638	23.87±8.959	24.64±9.591	-0.466
3	Slant Angle	84.23±12.662	87.69±10.955	0.099	85.17±12.078	86.00±12.511	-0.378
4	Height of Handwriting	70.47±13.230	72.34±13.542	-0.801	70.62±21.361	67.14±15.40	1.023
5	Aspect Ratio of Bigram 'th'	0.87±0.250	0.95±0.263	-1.737	0.77±0.213	0.72±0.188	1.327
6	Height Relation of 't' to 'h'	1.08±0.227	1.08±0.212	-0.063	1.08±0.177	1.12±0.204	-1.109
7	Pattern Matching of 'y' template	0.47±0.089	0.48±0.102	-0.221	0.44±0.085	0.43±0.093	0.759
8	Pattern Matching of 'm' template	0.39±0.069	0.40±0.054	-1.362	0.37±0.068	0.38±0.073	-1.014
9	Pattern Matching of 'd' template	0.50±0.085	0.50±0.075	-0.072	0.47±0.078	0.47±0.075	-0.250
10	Pattern Matching of 'f' template	0.49±0.116	0.48±0.100	0.445	0.44±0.101	0.44±0.089	-0.099
11	Pattern Matching of 't' template	0.48±0.085	0.49±0.082	-0.268	0.46±0.088	0.46±0.069	-0.146

Table 5- *Comparison of conventional (qualitative) handwriting features between writers of different cultural groups living in same geographical region (attending same school).*

S. No.	Handwriting Features	Categories of Features	Nagpur			Delhi		
			Brahmins	Scheduled Castes	Chi-Square	Brahmins	Scheduled Castes	Chi-Square
			n(%)	n(%)		n(%)	n(%)	
12	Alignment	Ascending	57(79.2)	47(78.3)	0.014	38(54.3)	34(60.7)	0.525
		Descending	15(20.8)	13(21.7)		32(45.7)	22(39.3)	
13	Presence of loop in 't' in bigram 'th'	Yes	15(20.8)	14(23.3)	0.119	5(7.0)	7(12.5)	1.090
		No	57(79.2)	46(76.7)		66(93.0)	49(87.5)	
14	Presence of loop in 'h' bigram 'th'	Yes	9(12.5)	11(18.3)	0.866	9(12.7)	7(12.5)	0.001
		No	63(87.5)	49(81.7)		62(87.3)	49(87.5)	
15	Pattern of Left Margin	Wide Left	3(4.2)	4(6.7)	0.766	14(19.7)	5(8.9)	3.951
		Narrow Left	35(48.6)	27(45.0)		29(40.8)	31(55.4)	
		No Left	21(29.2)	16(26.7)		4(5.6)	3(5.4)	
		Normal Left	13(18.1)	13(21.7)		24(33.8)	18(30.4)	
16	Pattern of Upper Margin	Wide Upper	3(4.2)	6(10.0)	4.087	17(23.9)	11(19.6)	0.927
		Narrow Upper	29(40.3)	17(28.3)		21(29.6)	15(26.8)	
		No Upper	37(51.4)	1(1.7)		31(43.7)	1(1.8)	
		Normal Upper	3(4.2)	36(60.0)		2(2.8)	29(51.8)	

Table 6- *Comparison of computational (quantitative) handwriting features among writers of different cultural groups living in different geographical regions (attending different schools).*

S. No.	Handwriting Features	Brahmins (Nagpur)	Scheduled Castes (Delhi)	t-value	Brahmins (Delhi)	Scheduled Castes (Nagpur)	t-value
		Mean±S.D.	Mean±S.D.		Mean±S.D.	Mean±S.D.	
1	Pen Pressure	0.72±0.024	0.75±0.021	-7.932***	0.74±0.019	0.72±0.030	6.175***
2	Handwriting Style (number of connected components)	24.53±9.682	24.64±9.591	0.947	23.87±8.959	21.78±9.462	1.297
3	Slant	84.23±12.662	86.00±12.511	-0.789	85.17±12.078	87.69±10.955	-1.241
4	Height of Handwriting	70.47±13.230	67.14±15.408	1.311	70.62±21.361	72.34±13.542	-0.538
5	Aspect Ratio of Bigram 'th'	0.87±0.250	0.72±0.188	3.729***	0.77±0.213	0.95±0.263	-4.301***
6	Height Relation of 't' to 'h'	1.08±0.227	1.12±0.204	-1.097	1.08±0.177	1.08±0.212	0.071
7	Pattern Matching of 'y' template	0.47±0.089	0.43±0.093	2.491**	0.44±0.085	0.48±0.102	-1.929*
8	Pattern Matching of 'm' template	0.39±0.069	0.38±0.073	0.375	0.37±0.068	0.40±0.054	-2.958**
9	Pattern Matching of 'd' template	0.50±0.085	0.47±0.075	2.008*	0.47±0.078	0.50±0.075	-2.482**
10	Pattern Matching of 'f' template	0.49±0.116	0.44±0.089	2.627**	0.44±0.101	0.48±0.100	-2.317*
11	Pattern Matching of 't' template	0.48±0.085	0.46±0.069	1.844	0.46±0.088	0.49±0.082	-2.117*

Table 7- *Comparison of conventional (qualitative) handwriting features among writers of different cultural groups living in different geographical regions (attending different schools).*

S. No.	Handwriting Features	Categories of Features	Brahmins (Nagpur)	Scheduled Castes (Delhi)	Chi-Square	Brahmins (Delhi)	Scheduled Castes (Nagpur)	Chi-Square
			n(%)	n(%)		n(%)	n(%)	
12	Alignment	Ascending	57(79.2)	34(60.7)	5.219*	38(54.3)	47(78.3)	8.255**
		Descending	15(20.8)	22(39.3)		32(45.7)	13(21.7)	
13	Presence of loop in 't' in bigram 'th'	Yes	15(20.8)	7(12.5)	1.537	5(7.0)	14(23.3)	6.960**
		No	57(79.2)	49(87.5)		66(93.0)	46(76.7)	
14	Presence of loop in 'h' bigram 'th'	Yes	9(12.5)	7(12.5)	0.000	9(12.7)	11(18.3)	0.805
		No	63(87.5)	49(87.5)		62(87.3)	49(81.7)	
15	Pattern of Left Margin	Wide Left	3(4.2)	5(8.9)	12.979**	14(19.7)	4(6.7)	15.281**
		Narrow Left	35(48.6)	31(55.4)		29(40.8)	27(45.0)	
		No Left	21(29.2)	3(5.4)		4(5.6)	16(26.7)	
		Normal Left	13(18.1)	18(30.4)		24(33.8)	13(21.7)	
16	Pattern of Upper Margin	Wide Upper	3(4.2)	11(19.6)	9.138*	17(23.9)	6(10.0)	5.504
		Narrow Upper	29(40.3)	15(26.8)		21(29.6)	17(28.3)	
		No Upper	37(51.4)	1(1.8)		31(43.7)	1(1.7)	
		Normal Upper	3(4.2)	29(51.8)		2(2.8)	36(60.0)	

groups have differences in their culture but they shared their schooling since beginning of their childhood, which could also be one of the answers for the aforementioned non-significant results. According to Huber and Headrick [1], the writing system which is taught to a child follows patterns popular within a particular region. This writing system becomes the habitual aspect of the writing of a child, which leads to similarity in the handwriting features of writers who have shared their region or schooling.

It is also important to mention here that writers of different cultural groups living in different geographical regions and attending different schooling systems (Table-6, 7) exhibited maximum number of significant differences (in comparison to the writers of same cultural groups who were living in different regions and attending different schools and writers of different cultures living in the same geographical region and studying in the same schools) in handwriting features. These findings constitute evidence that additive impact of culture and schooling environment plays the most significant role in influencing handwriting

features.

4. Conclusion

The evidence presented in this study suggests that the schooling environment of a writer plays a greater role in influencing handwriting of a writer as compared to the culture. Much of a writer's handwriting is controlled by the handwriting instructions which a writer receives in the schooling system. Findings from this study provide additional support to the fact that the nature or appearance of handwriting is primarily environment, experience and culture dependent [1]. It is expected that our results will assist document examiners in understanding the important role of schooling environment or teaching systems in influencing handwriting features and in providing the basis for future inquiry and research in another geographical region.

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Conflict of Interest

None.

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