Forensic Examination Of Handwriting To Study The Effect Of Broad-Tip Writing Instruments

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Abstract: *Handwriting is a neuromuscular task and a skill acquired by an individual. However, it is affected directly by constraints like writing surface, writing instrument, writing posture, age, mental and health conditions of the writer, etc., and changes in its general pictorial appearance. The present study was conducted to find the effect of broad-tip pens on handwriting characteristics compared to ballpoint pen writings and to establish the extent to which the handwriting prepared from different writing instruments can be comparable. Arrangement, absolute size, simplifications, embellishments, initial and terminal strokes, connections, line continuity, line quality, legibility, pen control (stroke width), and alterations were affected due to the use of broad-tip instruments. However, handwriting characteristics, including spacing, alignment, slant, class of allographs, letter formation, line continuity, relative size, and diacritic marks, remained unchanged qualitatively and statistically with the change of the writing instrument being employed. The change in the writing instrument sabotages the general pictorial appearance of handwriting. However, a close examination of the writings and the handwriting features can reveal substantial pieces of evidence in support of the similarity or dissimilarity of writings prepared by different writers. The ballpoint pen writings were most comparable to the checking pencil writings and least comparable to the plastic crayon writings.*

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Key words: Forensic handwriting examination, broad-tip writing instruments, chi-square analysis, element of writing identification, disguised handwriting, forgery.

1. Introduction

Handwriting, a preferred mode of written communication, is an individual's physical performance, and it is the transfer of ideas or thoughts occurring in the human brain using a hand-held writing instrument. Undeniably, the quality of the writing or a signature thus produced is affected in varying degrees, directly or indirectly, by several factors like the writing surface, writing substrate, writing instrument, writing posture, constrained spaces, age, and health conditions of the writer. Forensic document examiners are often asked to examine and report on cases involving the comparison of writings produced by different instruments. In a wider sense, writing instruments can be viewed as physical devices to record one's thoughts through written notes. Thus, a writing instrument empowers an individual to build and express his thoughts, ideas, feelings, and visions with sufficient clarity and proper perspective. However, the effects of the writing materials and working mechanisms of the writing devices could be responsible for the changed general appearance of the resultant writing in varying degrees. The change may be nominal in a few cases and material or significant in others.

Unfamiliarity with the characteristics of different types of writing instruments often comes in the way of handling such cases at the investigation stage or the

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trial stage (1). Due to their inherent characteristics, some writing instruments can hide certain details of letter formations (2-3). The writing characteristics of various writing instruments, such as fountain pens, ball-point pens, fiber-tipped pens, roller ball pens, gel pens, and pencils. Some of the instruments' writing characteristics can obscure the minute and inconspicuous details of letter construction to the extent of their being misinterpreted as evidence of forgery by simulation, hindering their forensic examination. Being economical, a ball-point pen containing a freely rotating steel ball of variable diameter enclosed in a pen housing continues to be the preferred choice for many writers (4). It was not always possible to distinguish clearly between the genuine signatures produced with a faulty ball-point pen and the faulty movement of the forger of a simulated signature. However, due to technological advancements, the quality of ball-point pens has since improved tremendously (5). It was then possible to produce strokes of variable width using a ball-point pen (6). The characteristics of various writing instruments and their effects on handwriting were discussed by different researchers (7-10). Further, the effect of the use of unconventional writing instruments like broad-tip cosmetic items like lipstick and surfaces like tissue paper on handwriting characteristics has been (11).

When examining a questioned document, it's important to consider the possibility of using unfamiliar writing instruments, such as markers, calligraphic pens, sketch pens, paint, highlighters, etc. These instruments could be used by a skilled writer to create a document. Additionally, unconventional writing mediums like lipstick, kajal, blood-stained fingertips, etc., could be used in certain situations. The wide variety of available writing materials and the lack of a comprehensive database of features affected by different writing instruments present new challenges for document examiners. This is particularly true when dealing with handwriting characteristics that are difficult to interpret.

Colored pencils, used as writing instruments, are primarily composed of four components: colorants, clay, binder, and lubricant. The inflexibility and quality of the writing tip of the colored pencil depend on the ratio of these key elements (12). Crayons appear to produce typically broad and greasy strokes depending on their thickness. Non-destructive comparison of pencil writings can be attempted to differentiate their color shades by visual, microscopic, and video-spectral comparison. Generally, the thickness of the writing line produced by a pen is related to its tip size. The larger the tip's size, the thicker the line it produces and, consequently, the lesser detail therein. Conversely, the smaller the tip's size, the more detail therein. Some other factors can also contribute to the width of the handwritten stroke besides the tip size. For example, the drier ink line is usually narrower than the wetter ink line from the same size nib (4,13).

The results of this study can, therefore, be helpful to forensic document examiners in making the most appropriate, objective decisions in such cases, as it will facilitate an effective comparison of handwriting characteristics, irrespective of the writing instrument involved in the writing process. Regardless of all the work done in this area of questioned documents, a descriptive study of handwriting characteristics originating from the broad tip writing instruments like checking pencils, sketch pens, and plastic crayons is either too scarce or not published. Hence, the aim of this study was to find out the extent to which the handwriting characteristics of the writing produced by such broad tip writing instruments, namely, the sketch pens, checking pencils, and plastic crayons viz-a-viz the widely used ball-point pens, are suitable for forensic examination and effective comparison with their normal writing samples Additionally, qualitative and statistical examination was also performed for better and more objective assessment, interpretation and appreciation of results.

2. Materials and Methods

2.1 Sample Preparation

A total of 600 handwriting samples were prepared by 50 individuals. The handwriting samples were prepared on plain A4 size 75 GSM white sheets of paper of Trident using a ballpoint pen, a sketch pen, a crayon, and a checking pencil (Table 1). A set of 13 sheets of paper attached to the paperboard was provided to the writers for the preparation of the handwriting specimens. The set of papers acted as padding for the writer. The handwriting specimens were prepared by 50 male and female individuals aged

S. No.	Writing instrument details (ID)	Tip Size	Minimum stroke width	Maximum stroke width
1	Cello Butterflow blue Ballpoint pen (BP)	1mm	0.2mm	0.5 mm
2	Stic Colorstix black Sketch pen (SP)	1mm	0.5mm	1.5 mm
3	Nataraj Checking Red-Blue Pencil (CP)	3mm (lead diameter)	0.5 mm	1 mm
4	Doms black plastic crayon (used) (PC)	1.5 mm	0.3mm	1.5mm
5	Doms black plastic crayon (unused) (PC)	3mm		

Table 1: The writing instruments used in the study, along with their tip width and range of stroke width they produce.

between 21 to 50 years. Volunteers were asked to write the following text along with their signatures.

"Erik was watching the quiz show when the doorbell rang. He quickly opened the door and saw a box lying there. He looked for the delivery man but found no one. He brought the box indoors and checked for the shipping address 'House No. 6782, 4035 Pearl Street, Canada'. He found a creepy doll in it. He just ran away in terror while dialing 911."

A triad of writings for each writing instrument was prepared by each writer. This resulted in the production of 150 samples each of ballpoint pens, sketch pens, checking pencils, and plastic crayons. Thus, a total of 600 samples were prepared. To overcome the constraint of writing position, the writing was executed in a comfortable sitting position. No further instructions regarding the execution of writing were given. Subjects were numbered from 1-50, and ballpoint pen, sketch pen, checking pencil, and plastic crayon were coded as BP, SP, CP, and PC, respectively, to give a unique identification number to each sample (Table 1).

2.2 Institutional Ethical Permission

Ethical permission was obtained as per rules from the Institutional Ethical Committee (IEC).

2.3 Analysis

The writings executed using a sketch pen, checking pencil, and plastic crayon by each individual were compared with the corresponding ballpoint pen writings. The characteristics of handwriting were analyzed with a magnifying lens of 3X magnification under a light source, as well as using a Nikon SMZ800N stereomicroscope (Tokyo, Japan) with a magnification of 2×10×8 X equipped with Nikon C-FLED2 LED light source and measuring templates.

The writings executed using various broad-tip writing instruments were compared with the writing of a ballpoint pen as standard. The handwriting features were compared in accordance with the elements of style as well as elements of execution suggested by Huber and Headrick, 2018 (14). To assess the arrangement of the writing, a variety of factors such as left, right, and top margins, the position of

signature in relation to the writing, arrangement of numerals in relation to preceding words, and placement of punctuation with respect to words were observed. These factors were further sub-categorized. Additionally, spacing between letters, words, and lines was analyzed. Writing alignment of words with an imaginary baseline was determined by examining the placement of words, signatures, or writing with respect to an imaginary baseline and classified as uphill, downhill, horizontal, or mixed. The absolute and relative size of the handwriting was measured using a graph printed on a transparent sheet and categorized as small, medium, or large. The slant of the writing was determined by measuring the angle of the axis of the letters with respect to the imaginary baseline and described as forward, backward, upward, or mixed slant. The formation of a particular letter, which is an individualistic characteristic of handwriting, was considered. The placement and the shape of the diacritic marks, such as i-dots, j-dots, and t-bars, were also observed. Simplification was considered present if slurring, omission, and alteration were observed in the writing. The presence or absence of embellishments was noted. The initial and terminal strokes were studied for their shape and length and were categorized as blunt, tapered, wedge-shaped, or mixed. Line quality was characterized by studying the rhythm and fluency, retouching/patching, pen lifts, tremors, and hesitations. Connections, legibility, thickness of the stroke, and alterations/corrections were also studied. The size of the writing tips and the minimum and maximum stroke thickness of the writings corresponding to these writing instruments were also measured (in millimeters) utilizing a measuring scale and stereomicroscope.

2.4 Statistical analysis

The results obtained qualitatively, examining the handwriting samples using different writing instruments, were analyzed statistically using Pearson's chi-square test. The null hypothesis (H_o) assumed that the writings prepared by ballpoint pen, sketch pen, checking pencil, and plastic crayon are comparable. If the null hypothesis is true:

$$P(BP) = P(SP) = P(CP) = P(PC)$$

Where P represents the probability of observed characteristic features in the English handwriting of the volunteers, 'BP' represents ballpoint pen, 'SP' represents sketch pen, 'CP' represents checking pencil, and 'PC' represents plastic crayon.

Thus, the alternate hypothesis would be that the writings prepared by ballpoint pen, sketch pen, checking pencil, and plastic crayon are not comparable to each other, that is,

$$P(BP) \neq P(SP) \neq P(CP) \neq P(PC)$$

The chi-square values (χT^2) were calculated by using the following formula,

$$\chi T^2 = \sum (O_i - E_i)/E_i$$

Where O represents the observed value, and E represents the expected value.

An Excel sheet was prepared for all the handwriting characteristics to calculate the Chi-square value. A 4x3 component table was drawn. Hence, the level of significance was 3, and the degree of freedom of 5% was chosen. The critical value of chi-square ($\chi a2$) was 7.815. The null hypothesis would be accepted for the value lower than the critical value, and for the chi-square value higher than the critical value, the null hypothesis would be rejected. The increased calculated chi-square value of a characteristic feature from the critical value depicted its statistical insignificance (15).

3. Results

3.1 Qualitative Analysis

The handwriting features, including arrangement, class of allograph, connections, design of allograph and their combinations, absolute size, relative size, slant, spacing, abbreviations/ simplification, alignment, initial and terminal strokes, diacritics and punctuations, embellishments, writing quality, line continuity, line quality, pen control (stroke width) were analyzed. The comparison between the writings made by broad-tip writing instruments, including a sketch pen, checking pencil, and plastic crayons, was performed with the standard writings produced by a ballpoint pen with respect to the discriminating elements suggested by Huber and Headrick (2018) and were categorized as changed (1) or unchanged (0), and an increase was depicted by (+) (Table 2-3). A comparison of the three broad-tip instrument writings with their corresponding ballpoint pen writings revealed the following observation.

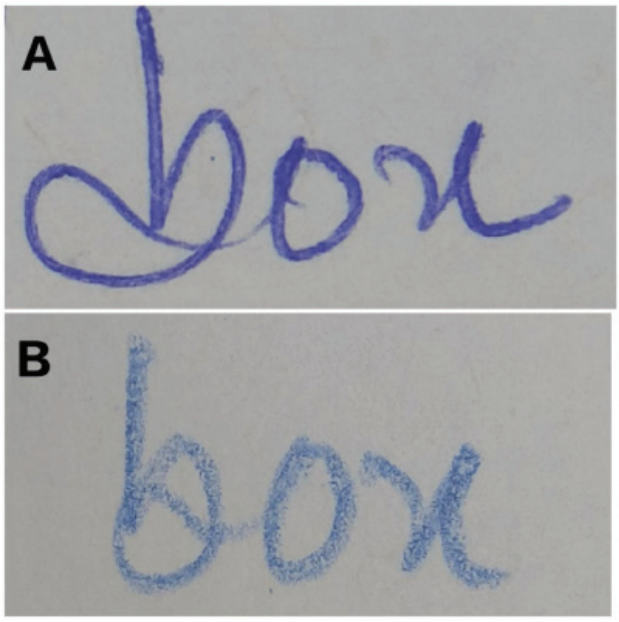

Fig. 1: Embellishment present in A) ballpoint pen writing and B) plastic crayon writing.

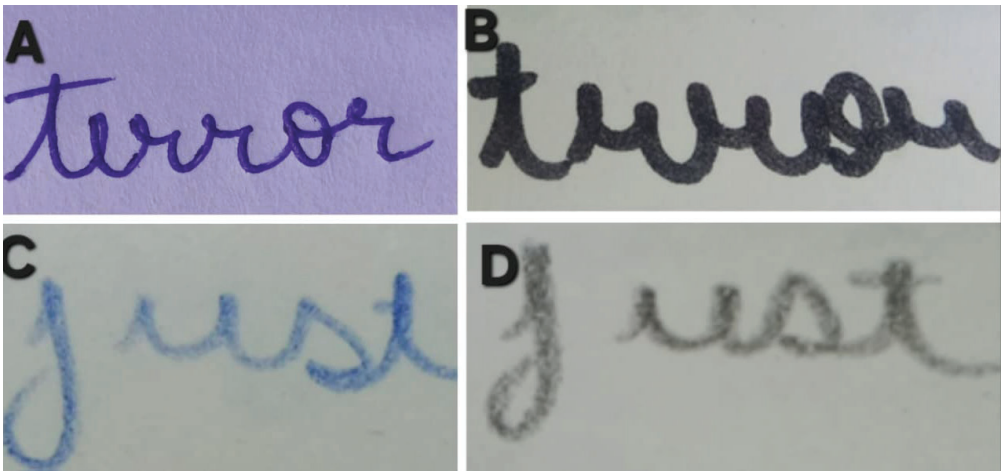

Fig. 2: Simplifications A) No omission observed in writing made by a ballpoint pen, B) Omission of 'e' in 'terror' in sketch pen writing. Omission of diacritic in 'j' in C) auditor's pencil writing, and D) plastic crayon writing.

- Significant changes were noticed in handwriting characteristics, simplifications, and embellishments in the broad-tip pen writings. There were increased simplifications in sketch pen, checking pencil, and plastic crayon writing. Comparatively lesser embellishments were observed in checking pencil writings (Fig. 1-2).
- Significant changes were also observed in the nature of initial and terminal strokes in all the broad-tip pen writings. Further, inconspicuous characteristics like the small hooks and ticks, which are less obvious but very significant, could not be observed in some of the broad tip writings, especially in the plastic crayon (Fig. 3-4).
- Significant changes were observed in the characteristics representing the intra-word and inter-word connections in broad-tip sketch pen writings. In contrast, the checking pencil and plastic crayon writings remained unchanged.
- Significant (drastic) changes were observed in the stroke thickness of the writings

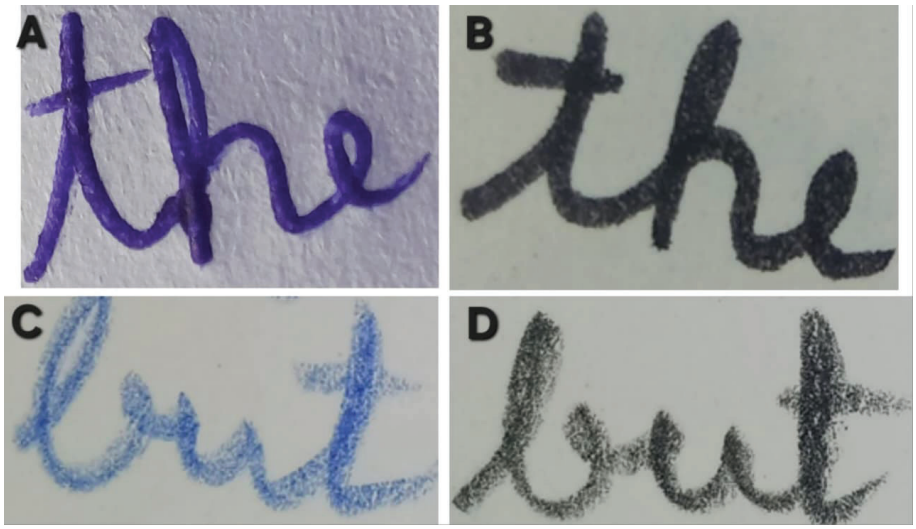

Fig. 3: A) Round initial stroke seen in ballpoint pen writing. Wedge-shaped strokes present at the initial position in broad-tip instrument writings: B) Sketch Pen, C) Auditor's Pencil, D) Crayon.

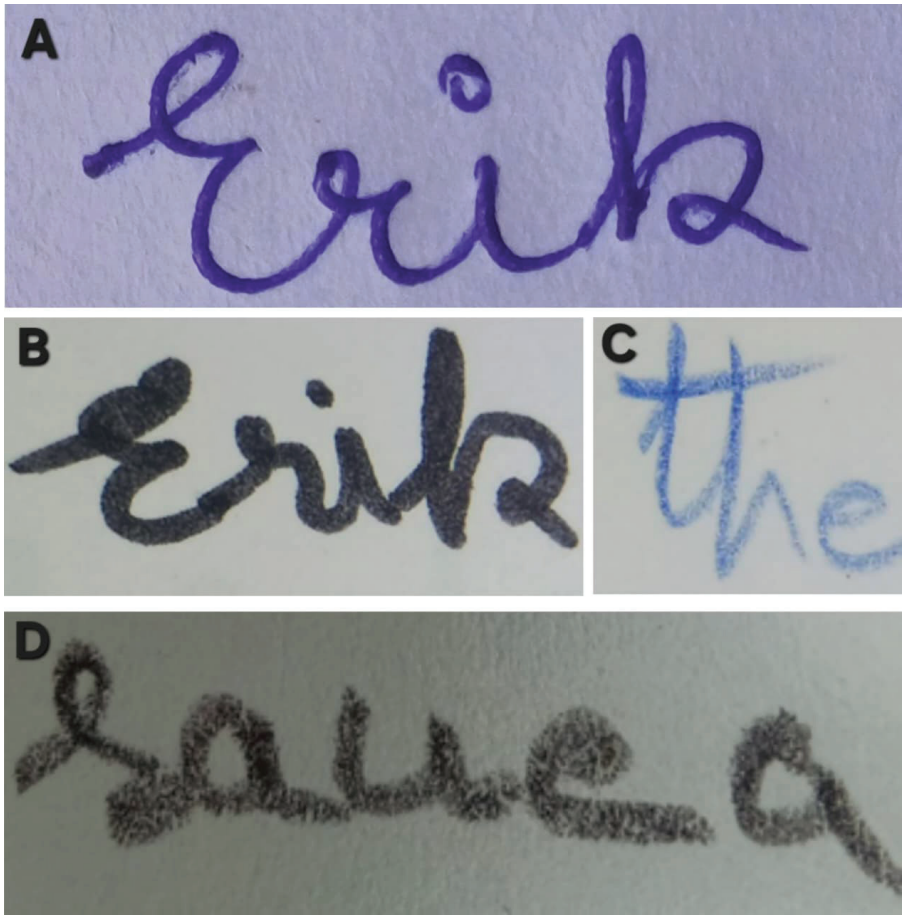

Fig. 4: A) Pointed terminal stroke as seen in ballpoint pen writing. Wedge-shaped strokes present at the terminal position in broad-tip instrument writings: B) Sketch Pen, C) Auditor's Pencil, D) Crayon.

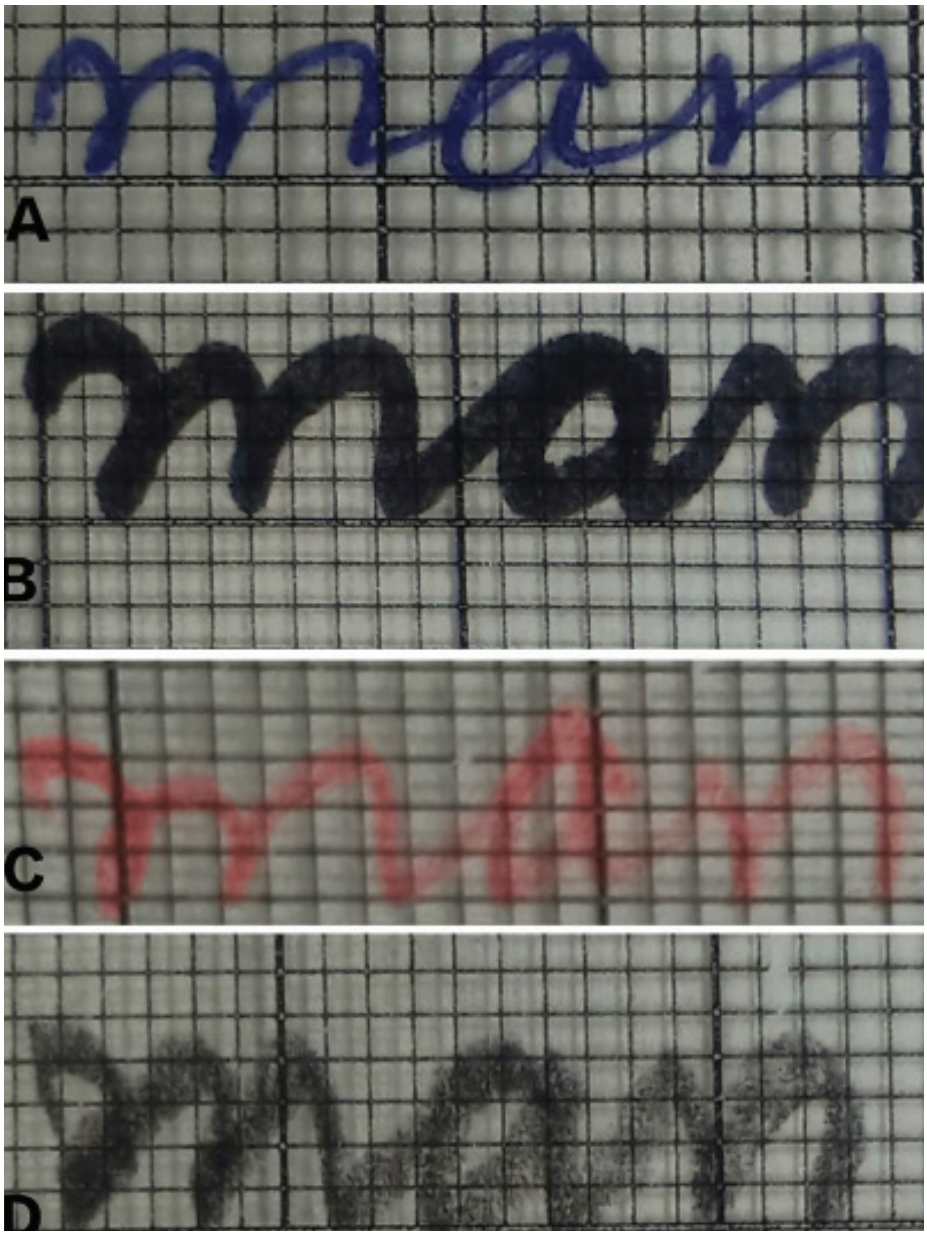

Fig. 5: A) Small-sized ballpoint pen writing, B) Medium-sized sketch pen writing, C) Medium-sized auditor's pencil writing, D) Medium-sized plastic crayon writing.

produced by all the broad-tip pen writings, which is generally attributable to the writing instrument's performance (Fig. 5).

- Significant changes resulting from alteration (correction) were observed in the broad-tip sketch pen and plastic crayon writings, thereby affecting their overall writing quality. In contrast, no such significant change was observed in the checking pencil writings.
- A significant change in size (i.e., increase) was observed in almost all the broad-tip pen writings. However, their relative size remained unchanged (Fig. 5).
- Interestingly, no significant change was observed in most of the line quality characteristics like the retouching/ patching, pen lifts, tremors, and hesitations in any of the broad-tip pen writings. However,

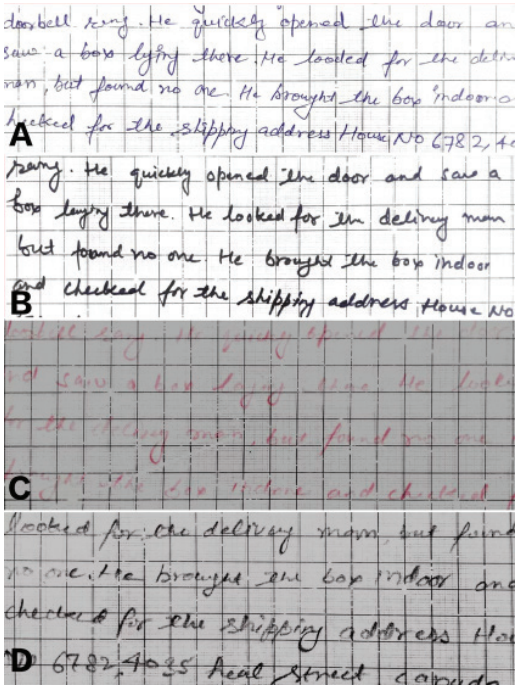

Fig. 6: Mixed alignment in A) Ballpoint pen writing, B) Sketch pen writing, C) Auditor's pencil writing, D) Plastic crayon writing.

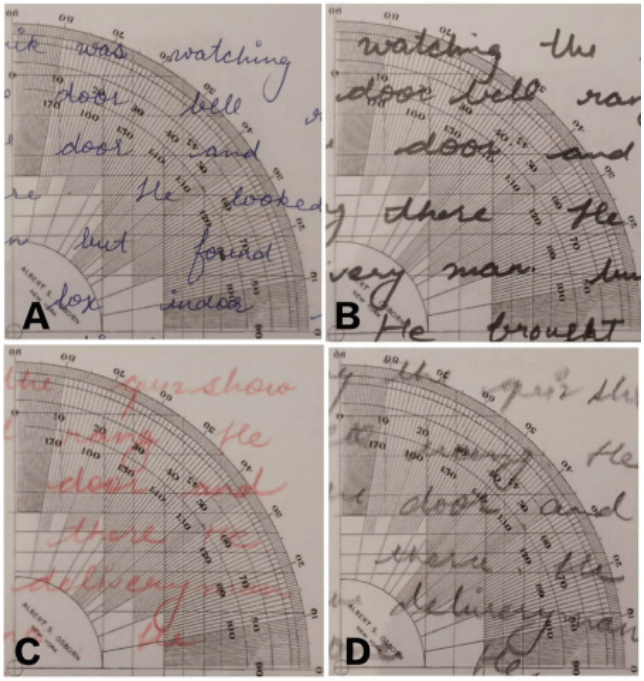

Fig. 7: A) Forward slant in A) Ballpoint pen writing (71 degrees), B) Sketch pen writing (64 degrees), C) Auditor's pencil writing (71 degrees), D) Plastic crayon writing (62 degrees).

S. No.	Elements of Style	Sketch Pen	Checking Pencil	Plastic Crayons
1	Arrangement	0	0	1
2	Class of Allograph	0	0	0
3	Connections	1	0	0
4	Design of Allograph and their combinations	0	0	0
5	Absolute size	1 +	1 +	1 +
6	Relative Size	0	0	0
7	Slant	0	0	0
8	Spacing	0	0	0

Table 2: Comparative study of the Elements of Style in Broad tip writings viz-a-viz ballpoint pen writing.

S. No.	Elements of Execution	Sketch Pen	Checking Pencil	Plastic Crayons
1	Abbreviations/ Simplification	1	1	1
2	Alignment	0	0	0
3	Initial and Terminal strokes	1	1	1
3 (a)	Hooks and ticks	1	1	1
4	Diacritics and Punctuations	0	0	0
5	Embellishments	1	1	1
6	Writing Quality	1	0	1
7	Line Continuity	0	0	0
8	Line Quality	1	0	1
9	Pen Control (Stroke Width)	1	1	1

Table 3: Comparative study of the Elements of Execution in Broad tip writings viz-a-viz ballpoint pen writing.

the characteristic representing rhythm and fluency showed a general decline in all the broad-tip pen writings.

- No significant change was observed in most of the writing arrangement characteristics like the left, right, and top margins, word alignment, and numerals-arrangement. However, plastic crayon writings showed a general lack of uniformity in their left margin, change in the position of the signature on the written page, and minute changes in the placement of punctuation marks.
- No significant change was observed in any of the spacing characteristics, namely the letter spacing, word spacing, line spacing, and alignment (Fig. 6).
- No significant change was observed in characteristics like the slant, letter formations, and diacritics in any of the broad-tip pen writings (Fig. 7).
- No significant change was noticed in the legibility of the checking pencil writings. However, significant changes indicating reduced legibility of the broad tip sketch pen and plastic crayon writings were observed at places.

Handwriting Characteristics	Description and Type	Expected value	Chi-Square value			
			Ballpoint pen	Sketch pen	Checking pencil	Plastic crayon
Left Margin	Narrow and uniform	6	0	0	0	0
	Narrow and non-uniform	33	0	0.0303	0.0303	0.1212
	Wide and uniform	3	0	0	0	0
	Wide and non-uniform	4	0.25	0.25	0	0
	Non-uniform	4	0.25	0	0.25	1
Right Margin	Narrow and uniform	0	-	-	-	-
	Narrow and non-uniform	38.75	0.0145	0.1306	0.0145	0.0145
	Wide and uniform	0	-	-	-	-
	Wide and non-uniform	4.5	0.0555	0.0555	0.0555	0.0555
	Non-uniform	6.75	0.0092	1.1203	0.2314	0.2314
Top Margin	Narrow and uniform	4	0	0	0	0
	Narrow and non-uniform	31.5	0.0714	0.0079	0.0079	0.0714
	Wide and uniform	1.25	0.45	0.05	0.05	0.05
	Wide and non-uniform	9.75	0.0064	0.0064	0.0576	0.0064
	Non-uniform	3.5	0.0714	0.0714	0.6428	0.6428
Alignment of words	Partly on line	26.75	0.0210	0.0023	0.0023	0.0023
	Mostly on line	23.25	0.0241	0.0026	0.0026	0.0026
Position of signature	Towards the right side	29.25	0.1730	0.1047	0.0021	0.0192
	Towards the left side	0.25	0.25	0.25	0.25	2.25
	Towards the centre	14.5	0.0172	0.1551	0.1551	0.0172
	At the end of writing	6	0.6666	0	0.1666	0.1666
Arrangement of numerals	In line	9.75	0.1602	0.0576	0.0064	0.0576
	Above	0	-	-	-	-
	Below	13	0.0769	0.0769	0	0
	Mixed	27.25	0.0022	0.0022	0.0022	0.0206

Table 4: Statistical analysis of arrangement as a handwriting feature.

Handwriting Characteristics	Description and Type	Expected value	Chi-Square value			
			Ballpoint pen	Sketch pen	Checking pencil	Plastic crayon
Connections	Present	34.5	0.0652	0.3550	0.0652	0.0072
	Absent	3	0	0	0	0
	Mixed	12.5	0.18	0.98	0.18	0.02

Table 5: Statistical analysis of connections as a handwriting feature.

Handwriting Characteristics	Description and Type	Expected value	Chi-Square value			
			Ballpoint pen	Sketch pen	Checking pencil	Plastic crayon
Size	Small	5.5	13.136	1.1363	0.4090	3.6818
	Medium	42.5	1.3235	0.0529	0.1470	0.2882
	Large	2	0.5	0.5	0.5	0.5

Table 6: Statistical analysis of dimensions as a handwriting feature.

Handwriting Characteristics	Description and Type	Expected value	Chi-Square value			
			Ballpoint pen	Sketch pen	Checking pencil	Plastic crayon
Slant	Forward	19	0.8421	0.0526	0.2105	0.0526
	Backward	0.75	0.0833	0.0833	0.0833	0.75
	Upward	0.5	0.5	0.5	0.5	0.5
	Mixed	29.75	0.4726	0.0021	0.0525	0.1701

Table 7: Statistical analysis of slant as a handwriting feature.

3.2 Statistical analysis

Using Pearson's chi-square test, a relationship between the writings made by ballpoint pens and broad-tip writing instruments was drawn. As shown in Tables 4-16, the chi-square value was less than the critical value for the characteristics representing the left, right, and top margins, alignment of words, the position of signature, arrangement of numerals, placement of punctuation marks, spacing between letters, words and lines, alignment, medium-sized writing, large sized writing, slant, diacritics, simplifications, embellishments, tapered, and mixed initial strokes, blunt, wedge-shaped and mixed terminal strokes, connections, rhythm/fluency, retouching/patching, pen-lifts, tremors, hesitations, legibility and the alterations. The null hypothesis was, therefore, acceptable for these features, indicating that the said characteristics from the broad-tip pens and the ball-point pens are inter-comparable.

Handwriting Characteristics	Description and Type	Expected value	Chi-Square value			
			Ballpoint pen	Sketch pen	Checking pencil	Plastic crayon
Spacing between letters	Narrow and uniform	15	0	0	0	0
	Narrow and non-uniform	34	0	0	0	0
	Wide and uniform	0	-	-	-	-
	Wide and non-uniform	0	-	-	-	-
	Non-uniform	1	0	0	0	0
Spacing between words	Narrow and uniform	7	1.2857	0	0	1.2857
	Narrow and non-uniform	23.25	0.0026	0.0026	0.2177	0.3252
	Wide and uniform	3.5	0.6428	0.0714	0.0714	0.0714
	Wide and non-uniform	4.25	0.0147	0.0147	0.1323	0.0147
	Non-uniform	12	0.0833	0	0.0833	0
Spacing between lines	Narrow and uniform	1	1	0	1	0
	Narrow and non-uniform	11.5	0.0217	0.1956	0.1956	0.5434
	Wide and uniform	1.5	0.1666	0.1666	0.1666	0.1666
	Wide and non-uniform	22.25	0.0028	0.0028	0.1376	0.0702
	Non-uniform	13.75	0.0045	0.2227	0.55	1.3136

Table 8: Statistical analysis of spacing as a handwriting feature.

Handwriting Characteristics	Description and Type	Expected value	Chi-Square value			
			Ballpoint pen	Sketch pen	Checking pencil	Plastic crayon
Simplifications	Present	34.75	0.2176	0.1456	0.0449	0.0161
	Absent	15.25	0.4959	0.3319	0.1024	0.0368

Table 9: Statistical analysis of simplifications as a handwriting feature.

Handwriting Characteristics	Description and Type	Expected value	Chi-Square value			
			Ballpoint pen	Sketch pen	Checking pencil	Plastic crayon
Alignment	Horizontal	14.5	0.1551	0.0172	0.1551	0.0172
	Uphill	7.5	0.0333	0.0333	0.0333	0.0333
	Downhill	6	0	0	0	0
	Mixed	22	0.0454	0.0454	0.04545	0.04545

Table 10: Statistical analysis of alignment as a handwriting feature.

Handwriting Characteristics	Description and Type	Expected value	Chi-Square value			
			Ballpoint pen	Sketch pen	Checking pencil	Plastic crayon
Initial strokes	Blunt	2.25	14.694	0.6944	2.25	2.25
	Tapered	0	-	-	-	-
	Wedge Shaped	2	2	0.5	2	0.5
	Mixed	45.75	0.3073	0.1106	0.0013	0.0341
Terminal strokes	Blunt	0	-	-	-	-
	Tapered	8	36.125	4.5	3.125	4.5
	Wedge Shaped	0	-	-	-	-
	Mixed	42	6.8809	0.8571	0.5952	0.8571

Table 11: Statistical analysis of commencements and terminations as a handwriting feature.

Handwriting Characteristics	Description and Type	Expected value	Chi-Square value			
			Ballpoint pen	Sketch pen	Checking pencil	Plastic crayon
i,j-dots	Dots	1.25	1.25	6.05	1.25	0.05
	Ticks	0.25	2.25	0.25	0.25	0.25
	Circles	1	1	1	0	0
	Mixed	47.5	0.0052	0.0473	0.0473	0.0052
t-bars	From the center	34	0	0	0	0
	Above the center	13	0	0	0	0
	Below the center	3	0	0	0	0
Placement of punctuation marks	In line	18.5	0.0135	0.0135	0.0135	0.1216
	Above	17	0	0	0	0
	Below	0.75	0.0833	0.0833	0.0833	0.75
	Mixed	13.75	0.0045	0.0045	0.0045	0.0409

Table 12: Statistical analysis of diacritics and punctuations as a handwriting feature.

Handwriting Characteristics	Description and Type	Expected value	Chi-Square value			
			Ballpoint pen	Sketch pen	Checking pencil	Plastic crayon
Embellishments	Present	12	0.3333	0	0.3333	0
	Absent	38	0.1052	0	0.1052	0

Table 13: Statistical analysis of embellishments as a handwriting feature.

Handwriting Characteristics	Description and Type	Expected value	Chi-Square value			
			Ballpoint pen	Sketch pen	Checking pencil	Plastic crayon
Legibility	Legible	46	0.0869	0.0217	0.0217	0.0869
	Illegible	4	1	0.25	0.25	1
Alterations / Corrections	Present	40.25	0.5605	0.0388	0.3493	1.3059
	Absent	9.75	2.3141	0.1602	1.4423	5.391

Table 14: Statistical analysis of legibility and writing quality as a handwriting feature.

Handwriting Characteristics	Description and Type	Expected value	Chi-Square value			
			Ballpoint pen	Sketch pen	Checking pencil	Plastic crayon
Rhythm/Fluency	Rhythmic	43.25	0.7644	0.0130	0.013	1.2153
	Less rhythmic	6.25	4.41	0.25	0.01	7.29
	Non- rhythmic	0.5	0.5	0.5	0.5	0.5
Retouching/ patching	Present	45.5	0.1373	0.0494	0.0054	0.0054
	Absent	4.5	1.3888	0.5	0.0555	0.0555
Pen-lifts	Present	40.5	0.0061	0.0061	0.0061	0.0555
	Absent	9.5	0.0263	0.0263	0.0263	0.2368
Tremors	Present	1.75	2.8928	0.3214	0.3214	0.3214
	Absent	48.25	0.1049	0.0116	0.0116	0.0116
Hesitations	Present	2.5	0.8823	0.098	0.098	0.098
	Absent	47.5	0.0473	0.0052	0.0052	0.0052

Table 15: Statistical analysis of line continuity and line quality as a handwriting feature.

Handwriting Characteristics	Description and Type	Expected value	Chi-Square value			
			Ballpoint pen	Sketch pen	Checking pencil	Plastic crayon
Thickness of stroke	Fine	12.5	112.5	12.5	12.5	12.5
	Broad	13	13	105.30	13	9.307
	Variable	24.5	24.5	24.5	26.54	22.54

Table 16: Statistical analysis of pen control as a handwriting feature.

On the other hand, for features like small-sized writings, blunt initial strokes, tapered terminal strokes, and stroke thickness, the chi-square value exceeded the reported critical value, and consequently, the null hypothesis was liable to be rejected. Therefore, the alternate hypothesis was acceptable. Hence, the said characteristics originating from the ballpoint pen writings are not comparable with those from the broad tip pens. The aforementioned statistical analysis is consistent with the independent qualitative assessment of the above handwriting features, thereby enhancing the reliability of the results of the present study.

4. Discussion

As stated by Harrison (2011), style characteristics may be considered insignificant by some people for the identification of handwriting. However, in the absence of suitable and sufficient personal characteristics of the writer, such as in the case of an anonymous letter or (in rather too limited) disguised and distorted writings, they may be considered valuable in the initial stage of investigation, particularly to determine the nationality of writer or more correctly, the country where the suspect writer was taught to write. The results of the present study reveal that most of the handwriting details remained unaffected by the change in the writing instrument. No significant changes were

observed while comparing spacing, alignment, slant, class of allographs, letter formation, line continuity, relative size, and diacritic marks made by broad-tip pen writings and ballpoint pen writings. According to Osborn (1929), the writing point does affect a few writing characteristics. However, the writing of a pen can be compared to the writing of a pencil because their basic properties, though different in both these instruments, do not materially affect the writing, making it possible to be compared. Subsequently, Mathyer (1969) stated that the text written using a pencil can be effectively compared with the one made with a pen or vice versa. However, comparing the writings made with a similar kind of writing instrument is preferable.

Certain writing features showed variations with the change in nature of the writing tip employed. Although, in the present study, no significant changes were observed in the arrangement and connections made by broad-tip pen writing compared to the ballpoint writings, slight changes in the placement of punctuation marks and connections were observed in the writings made by plastic crayons and sketch pens, respectively. This may be attributable to the writer's unhabitual or unaccustomed usage of broad-tip pens. Huber and Headrick (2018) also stated that the writing arrangement is a group of habits comprising the elements of one's style that are influenced by the writer's artistic ability, sense of proportion, and the instruction received. Therefore, the same cannot be equated with the personal characteristics or individual habits of the writer for their identification. Further, with repeated use and adaptability to the broad-tip instruments by a writer, their net effect on handwriting characteristics can be safely minimized or eliminated in due course of time. Masson (1985, 1992), in the context of felt-tip, fiber-tip, and ballpoint pens, also confirmed that writing habits remained unchanged irrespective of the writing instrument and, therefore, identification of authorship was possible.

Writing quality (or legibility) and the line quality of the writing made by broad-tip pens showed a general decline vis-a-vis the corresponding ballpoint pen writing, especially in the case of writings made with sketch pens and plastic crayons. This is probably the consequence of the broad tip size of the writing instrument which has the potential of masking the fine detail of letter construction. The result of the present study is consistent with the observations of Hilton (1984) that the broad tip pen writings overshadow certain handwriting features, whereas, fine point tip pens bring out the fine details of an individual's writing. Further, the interaction between inks associated with different kinds of writing instruments and the writing surface affects the general pictorial appearance of the writing.

Further, as stated by Harrison (2011), it is almost certain that the writing instrument has an effect that extends beyond that of the obvious difference in pictorial appearance to the extent that a clear outline, marked shading, and the finest details of the letter design could result from a fine flexible pen, whereas, a blunt pencil would not produce such shading or fine detail in the construction of letters, even by the most skilled writer. A ball-point pen may have all the faulty characteristics of a blunt pencil. Fortunately, the brain which controls the hand remains the same. This being so, irrespective of the writing instrument's nature, the handwriting's fundamental structure remains unaltered despite the changed general appearance and the amount of detail present in the handwritten strokes of the writing. Hence, an experienced document examiner should be capable of making effective comparisons between the writings produced by different types of writing instruments, provided that the writing standards are otherwise suitable and sufficient for comparison.

Handwriting characteristics related to the absolute size of the writing, simplifications, initial and terminal strokes, embellishments, and stroke width were changed significantly in sketch pen, checking pencil, and plastic crayon writings due to the broad tip of these writing instruments. These observations are consistent with the statement made by Saini (2015) and Thareja *et al.* (2019) that the quality of the strokes was slightly affected by a change in the writing instrument. However, despite such change, a document examiner can reach an opinion while comparing writings prepared by different writing instruments if the examiner is well aware of the working and distinctive characteristics of various writing instruments. Further, inconspicuous details in an individual's writing can assist the document examiner in reaching a definite opinion regarding its identification.

It has been observed that closed loops and eyelets, closed bodies, and the absence of spurs

changed the general appearance of the writing in broad-tip pen writings, probably due to the broad tip size of the writing instrument. Further, as observed in the present study, an increase in the number of simplifications in the case of broad-tip pen writings can be attributable to either or all of its tip size, increase in speed, or tiredness of the writer. As stated by Huber and Headrick (2018), line width, or stroke thickness caused by a free and rhythmically moving writing instrument, is a significant element of execution linked with the pen control concerning the management of the writing instrument by the hand in generating a writing line. Further, mature writings, executed with speed and fluency, seldom displayed the same magnitude of variation in stroke width. It will also be relevant to keep in mind the recommendation of Mathyer (1969) that, as far as possible, signatures executed with similar writing instruments should be used for comparison.

The results of the present study also revealed that significant and drastic changes were observed in the stroke thickness of the writings produced by all the broad tip instruments in comparison to the corresponding ball-point writings, which is generally attributable to the writing instrument's performance. These results are consistent with the earlier observations made by Osborn (1929) that a change in the pen will affect writing by changing the strength or width of the line, and a stub pen may change the location of the apparent shadings, which, however, are not due to increased pressure but to the relation of the stroke to the width of the point of the pen. A stub pen thus changes the appearance of the writing very materially, although not in any really fundamental manner. A pen of any kind may be in such poor condition that it will hardly write at all, but the work of a pen in this condition is easily recognized. Thus, the present study's results agree qualitatively and statistically with those of earlier studies.

5. Conclusions

The nature of writing instruments has a tendency to affect the writing in a lot of ways. The broad-tip pen writing may overshadow certain handwriting features, whereas fine-point-tip pens bring out the fine details of an individual's writing. The change in the writing instrument sabotages the general pictorial appearance of handwriting. However, a close examination of the writings and the handwriting features can reveal substantial evidence in support of the similarity or dissimilarity of writings prepared by different writers. For this purpose, writing samples were obtained from 50 subjects and analyzed for a set of general characteristics. The observations were made qualitatively and statistically. Writing habits, including spacing, alignment, slant, class of allographs, letter formation, line continuity, relative size, and diacritic marks, remained unaffected by the influence of the writing instrument being employed. However, handwriting characteristics, including arrangement, absolute size, simplifications, embellishments, initial and terminal strokes, connections, line continuity, line quality, legibility, pen control (stroke width), and alterations, were affected by the use of broad-tip instruments. The results of the analysis also depicted that ballpoint pen writing was most comparable to checking pencil writings, then with sketch pen writing, and least comparable to plastic crayon writing. On the whole, writings prepared by fine writing points and broad writing tips could be compared to each other only when the examiner has sufficient awareness about the working, characteristic features and quality of the writing instruments, other writing conditions as well as the extent of the natural variation in the writing of an individual. In addition to this, the availability of ample amounts of standards and materials is required for the purpose of comparison. Therefore, it becomes imperative to ensure that the document examiner always remains aware and updated regarding the characteristic features of the writings produced by different categories of writing instruments available in the market, including the broad-tip type. Apparently, there is wide scope for further research in this area because of the diversity of the writing materials and easy accessibility to larger tip-sized pens of all the categories. However, the same is likely to be extended shortly to cover additional writing materials available, or accessible to the common man.

List of abbreviations

BP- Ballpoint Pen
SP- Sketch Pen
CP- Checking Pencil
PC- Plastic Crayons

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