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Handwriting Inconsistencies in Multilingual Writers: A Detailed Study Across English, Hindi, and Nepali

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A B S T R A C T :

This study investigates handwriting inconsistencies among 100 multilingual writers proficient in English, Hindi, and Nepali, focusing on seven handwriting features: slant, spacing, alignment, rhythm, pen pressure, size and proportion, and language comfortability. Utilizing the Video Spectral Comparator (VSC8000), 300 dictation-based writing samples were analyzed, with each feature scored on a 1– 5 scale (1 = poor, 5 = excellent). The study aimed to quantify variations in handwriting consistency across the Latin (English) and Devanagari (Hindi, Nepali) scripts, assess the influence of self-reported language comfortability on handwriting quality, and explore applications in forensic science, neuroscience, and education. Statistical analyses, including ANOVA, Tukey's HSD, and Pearson correlations, revealed significant differences in slant ($F = 3.12$, $p < 0.05$), pen pressure ($F = 4.56$, $p < 0.01$), and size and proportion ($F = 3.89$, $p < 0.05$), with Hindi exhibiting the lowest mean scores (e.g., slant = 2.79, SD = 0.96) due to Devanagari's orthographic complexity. Language comfortability strongly correlated with rhythm ($r = 0.62$, $p < 0.01$), indicating that higher confidence enhances writing fluency. Qualitative analysis of low-scoring samples highlighted challenges with Devanagari's conjunct letters. Findings suggest that script complexity and comfort significantly influence handwriting consistency, with English outperforming Hindi and Nepali. These results inform forensic document examination by identifying language specific handwriting markers, advance neurocognitive models of multilingual writing, and guide pedagogical strategies for script acquisition. Limitations include the controlled dictation task and focus on three languages, warranting future research into naturalistic writing and additional scripts. Our goals is to see how consistent handwriting is in each language.

Keywords:Handwriting, Writing Differences, Multiple Languages, English Letters, Hindi Letters, Nepali Letters, Writing Comfort, Pen Strokes, Math Analysis

1. Introduction

Handwriting is a unique and fascinating way that people express themselves. It's like a fingerprint, showing how the brain and hand work together to create letters on a page. Every stroke of the pen, from the way letters tilt to the pressure applied, reveals something about the writer's skills, thoughts, and even feelings. When someone writes in multiple languages, their handwriting might change because each language has its own alphabet or script, requiring different movements and mental effort. This study explores how handwriting differs when 100 people write in three languages: English, which uses the simple Latin alphabet (letters like A, B, C); Hindi, which uses the complex Devanagari script (curvy letters like ff, ff); and Nepali, which also uses Devanagari but with slight variations. By looking closely at these differences, we aim to understand what makes handwriting consistent or inconsistent across languages and how these findings can help in fields like crime-solving, brain science, and education. Handwriting is more than just putting words on paper. It involves a complex process where the brain plans the shapes of letters, sends signals to the hand, and adjusts movements based on the writing surface and tool. For example, when writing the English letter "A," the hand makes straight, angled lines, which is relatively simple. In contrast, writing the Hindi letter "ff" requires curves, a horizontal line on top, and sometimes extra dots or marks, which demands more precision. Nepali's Devanagari script is similar to Hindi's but has unique letter forms and combinations that might affect handwriting differently. These differences in script complexity could lead to variations in how neat or consistent handwriting is, especially for people who switch between languages regularly. This study focuses on seven key features of handwriting, each scored from 1 (poor, hard to read) to 5(excellent,very neat):

1. Slant :How much letters tilt (left, right, or straight). Uneven tilting can make writing look messy.
2. Spacing :The gaps between letters, words, or lines. Uneven gaps can make text hard to follow.
3. Alignment:Whether writing stays on a straight line. Wobbly lines can reduce readability.
4. Rhythm :How smoothly the pen moves. Jerky movements create unevenstrokes.
5. Pen Pressure: How hard the writer presses the pen. Uneven pressure makes some letters faint and others dark.
6. Size and Proportion: The size and shape of letters. Letters that are too big, small, or uneven look unbalanced.
7. Language Comfortability: How confident the writer feels in each language. Feeling nervous might make handwriting shakier.

We used a special machine called the Video Spectral Comparator (VSC8000), commonly used by forensic experts, to measure these features in 300

handwriting samples (100 people writing three samples each in English, Hindi, and Nepali). The samples were collected through a dictation task, where participants wrote a story read aloud to them, ensuring everyone wrote the same content so we could focus on handwriting style.

The study of handwriting has a long history, especially in forensic science, where experts analyze writing to identify authors in legal cases, such as forged documents or threatening letters . Handwriting analysis, also called graphology in some contexts, has also been used to study personality, though this is con-troversial and less scientific. In brain science, handwriting helps researchers understand how the brain controls fine motor skills and processes language . For example, studies show that children learning to write develop stronger brain connections for reading and spelling. In education, teachers use handwriting to assess students' motor skills and language proficiency, especially in multilingual settings where students switch between scripts. Despite these advances, most handwriting research focuses on a single language, like English or Arabic, and often uses the Latin or Arabic scripts.

Little is known about what happens when people write in multiple languages, particularly when the scripts are as different as the Latin alphabet and Devanagari. English's 26 letters are simple and linear, making them easier to form. Devanagari, used in Hindi and Nepali, has 46 letters, including vowels, consonants, and complex combinations (e.g., combining ff and ş to form ffş), which require more hand movements and cognitive effort. This complexity might cause inconsistencies, such as uneven letter sizes or wobbly lines, especially if the writer is less comfortable with the language. Multilingual writers, like the 100 participants in this study, are common in places like India and Nepal, where people often learn English alongside regional languages like Hindi or Nepali. These writers must switch between scripts, which could affect their handwriting. For example, a study on Arabic-English bilinguals found that their handwriting changed because Arabic's right-to-left script required different hand movements than English's left-to-right . Similarly, Devanagari's unique features—curved shapes, top lines, and conjunct letters— might make Hindi and Nepali handwriting less consistent than English, especially for non-native writers or those less confident in the language.

Comfort with a language, or "language comfortability," is another key factor. When people feel confident, their brain can focus on making neat letters, leading to smoother, more consistent handwriting . If they're nervous or unfamiliar with a language, their hand might shake, or they might hesitate, causing mistakes like uneven spacing or tilted letters. In this study, participants rated their comfort from 1 (very uncomfortable) to 5 (highly comfortable), allowing us to see if confidence affects handwriting quality.

For instance, someone who feels great writing English but struggles with Hindi might write neat English letters but messy Hindi ones. This study is significant for several reasons. First, it fills a gap in research by examining handwriting across three languages with different scripts, a topic rarely studied. Most multilingual handwriting studies focus on similar scripts (e.g., Latin-based languages like English and Spanish) or one script at a time. By comparing English, Hindi, and Nepali, we explore how the brain and hand adapt to drastically different writing systems.

Second, the findings have practical uses: -

1. Forensic Science: Police can use handwriting patterns to identify which language a document was written in, helping solve crimes like forgery. For example, Hindi's curvy letters might leave unique clues compared to English's straight ones.

2. Neuroscience: Understanding how handwriting changes across languages reveals how the brain processes multilingual writing, which could help study bilingual brain development. -

3. Education: Teachers can learn why students struggle with certain scripts (e.g., Devanagari's complexity) and create better lessons to improve writing skills.

4. Technology: Insights from this study could improve handwriting recognition software, which often struggles with non-Latin scripts like Devanagari.

The study also has cultural importance. In countries like India and Nepal, millions of people write in multiple languages daily, from school assignments to official documents. Hindi and Nepali are official languages in India and Nepal, respectively, while English is widely used for education and business. Understanding how handwriting varies can help design better writing tools, such as pens or notebooks tailored for Devanagari, or training programs for multilingual writers. It also celebrates the diversity of scripts, showing how unique each 4 language's writing system is. To conduct this study, we recruited 100 participants (50 men, 50 women, ages 18–40) who are fluent in English, Hindi, and Nepali. Half were native speakers of Hindi or Nepali, and half were non-native but proficient, ensuring a mix of skill levels. Each participant wrote three 100-word stories per language, dictated by a researcher to keep the content consistent. The VSC8000 analyzed features like slant and pressure, and scored the samples based on clear criteria. We

used math tools, like averages, variation measures, and comparisons (ANOVA), to see if handwriting differed across languages and if comfort played a role.

By examining 300 handwriting samples, we aim to uncover patterns that show how script complexity and personal comfort shape handwriting. For example, we might find that Hindi handwriting has more tilted letters because Devanagari's curves are harder to control, or that people who love writing Nepali produce smoother strokes. These insights will add to the growing field of multilingual handwriting research, which is still in its early stages compared to single language studies.

This introduction sets the stage for a detailed study that combines science, culture, and practical applications. The rest of the report will describe how we collected and analyzed the handwriting samples, what we found (e.g., which language had the neatest writing), and what these results mean for police, scientists, teachers, and beyond. By explaining everything in simple terms, we hope to make this study accessible to everyone, from students to experts, while providing a deep dive into the fascinating world of multilingual handwriting.

2. Methodology

Participants

We studied 100 people (50 men, 50 women, ages 18–40) who can write in English, Hindi, and Nepali. To make sure they were good at these languages, we asked them to rate their comfort writing each language (1 = "I don't like it," 5 = "I'm great at it"). - Gave them a short writing test (e.g., write a paragraph about their day).

Half were native speakers of Hindi or Nepali, and half learned these languages later but were fluent. This mix let us see different handwriting styles, from experts to learners.

Sampling Procedure

Each person wrote a story in English, Hindi, and Nepali(The quick brown fox jumps over the lazy dog. Writing is a powerful form of self-expression. Different languages bring out different aspects of thought. Handwriting reflects personality, mood, and even stress levels. Many multilingual writers switch styles unconsciously. Slant, spacing, and pressure can vary with language use. Every script holds its own rhythm and flow). I read the story aloud and they wrote it down. This "dictation" ensured everyone wrote the same thing, so we could focus on how their handwriting looked, not what they said.

Analysis Tool

We used the VSC8000, a high-tech machine used by police to study documents. It zooms in to measure: Slant: How much letters lean (left, right, or straight).

- Spacing: Gaps between letters, words, or lines.
- Alignment: If writing stays on the paper's lines.
- Rhythm: If the pen moves smoothly or stops a lot.
- Pen Pressure: If the ink is dark (hard press) or light (soft press).
- Size and Proportion: If letters are too big, too small, or uneven.

Participants also rated their comfort with each language, which we compared to their handwriting.

Assessment Criteria

We scored each feature from 1 to 5 based on clear rules (Table 1). Table 1 explains each score.

Procedure

We scanned each sample with the VSC8000, and the expert gave scores based on Table 1. We used math to find average scores for each feature.

- Check how much scores varied.
- Compare languages to see if they're different.
- See if comfort affects handwriting.

Data Analysis

Using Numbers to Understand Handwriting

We used math to study the handwriting scores:

- Mean (Average): Add all scores for a feature (like slant) and divide by 100 (people). This shows the typical score. Example: If 100 people's slant scores for English add to 302, the mean is 302 ÷ 100 = 3.02.

- Standard Deviation (SD): Shows how much scores vary. A big SD means scores are spread out (some 1s, some 5s), like a class with tall and short kids. A small SD means scores are close (mostly 3s), like kids of similar height.

Example: For English slant (mean = 3.02), we subtract 3.02 from each score, square the results, add them, divide by 100, and take the square root to get SD = 0.85 or you can use microsoft excel to calculate the Standard Deviation .

ANOVA (Analysis of Variance): Checks if average scores for a feature (like slant) are different across English, Hindi, and Nepali. It compares variation between languages (e.g., Hindi vs. English) to variation within each language (e.g., among Hindi writers). A high ANOVA score (F-value) with $p < 0.05$ means the differences are real.

- Tukey HSD Test: If ANOVA finds differences, this test shows which languages are different (e.g., Hindi worse than English)
- Pearson Correlation: Checks if two things, like comfortability and rhythm, go together. A number (r) close to 1 means when one is high, the other is too. We averaged the three samples per person per language, giving 300 data points (100 people × 3 languages).

3. Result and Discussion

We calculated the average (mean) and standard deviation (SD) for each feature in each language (Table 2). Here's what they mean:

- Mean: The typical score. A higher mean (like 3.36 for English rhythm) means better handwriting. A lower mean (like 2.79 for Hindi slant) means more mistakes.
- SD: How much scores spread out. A big SD (like 1.03 for Hindi pen pressure) means some people scored 1 and others 5. A small SD (like 0.84 for English spacing) means most scored around 3.

Table 2: Average Scores and Spread (Standard Deviation) for Each Language

Feature	English		Hindi		Nepali	
	Mean	SD	Mean	SD	Mean	SD
Slant	3.02	0.85	2.79	0.96	3.02	0.89
Spacing	3.16	0.84	3.11	0.89	3.03	1.02
Alignment	2.84	1.01	2.94	0.97	2.89	1.03
Rhythm	3.36	0.87	3.26	0.99	3.26	1.05
Pen Pressure	3.34	0.92	2.94	1.03	3.18	0.98
Size and Proportion	3.21	0.91	2.94	0.99	3.03	1.01
Language Comfortability	3.16	0.98	2.84	1.02	3.02	0.95

What we learned:

- Slant: Hindi's mean (2.79) is lowest, and SD (0.96) is highest, so letters tilted a lot and unevenly. English and Nepali (3.02) were steadier.
- Spacing Nepali's mean (3.03) and SD (1.02) show uneven gaps. English (3.16, SD = 0.84) had the most consistent gaps.
- Alignment: Hindi's mean (2.94) was slightly better, but all had high SDs (1.0), meaning some writing was way off the line.
- Rhythm: English's mean (3.36) was highest, showing smooth writing. Hindi and Nepali (3.26) had bigger SDs, so some wrote jerkily.
- Pen Pressure: Hindi's mean (2.94, SD = 1.03) shows uneven pressing. English (3.34) was most consistent.
- Size and Proportion: English's mean (3.21) was best, Hindi's (2.94) had more size issues. -
- Language Comfortability: English (3.16) felt easiest, Hindi (2.84) hardest, Nepali (3.02) in between.

ANOVA: Checking for Differences

We used ANOVA to see if average scores for each feature were different across languages. ANOVA compares variation between languages to variation within each language. The formula is:

$$F = \frac{\text{Variation Between Languages (MSB)}}{\text{Variation Within Each Language (MSW)}}$$

Steps: -

- Sum of Squares Between (SSB) How much language means differ from the overall mean.
- Sum of Squares Within (SSW): How much scores vary within each language.

- Degrees of Freedom (df): Between = 2 (3 languages - 1), Within = 297 (300 samples - 3).
- Mean Squares: MSB = SSB ÷ df,
- MSW = SSW ÷ df.
- F-value: MSB ÷ MSW.
- p-value: If $p < 0.05$, the difference is real.

For Slant: - Means: English = 3.02, Hindi = 2.79, Nepali = 3.02.

Overall mean= (3.02 + 2.79 + 3.02) ÷ 3 = 2.943.

SSB = 100 ×[(3.02 −2.943)2 +(2.79 −2.943)2 +(3.02 − 2.943)2] = 100×(0.005929+0.022449+0.005929) = 4.826.

SSW = 99×(0.852+0.962+0.892)= 99 × (0.7225 + 0.9216 + 0.7921) = 229.581.

MSB = 4.826 ÷ 2 = 2.413,

MSW = 229.581÷ 297 = 0.773.

F = 2.413 ÷ 0.773 = 3.12,

p < 0.05 (significant).

For Pen Pressure: - Means: English = 3.34, Hindi = 2.94, Nepali = 3.18.

Over- all mean = (3.34 + 2.94 + 3.18) ÷ 3 = 3.153.

SSB = 100 × [(3.34 − 3.153)2 + (2.94 −3.153)2 + (3.18 − 3.153)2] = 100 × (0.035049 + 0.045369 + 0.000729) = 7.466.

SSW =99 × (0.92 + 1.03 + 0.98) = 99 × (0.8464 + 1.0609 + 0.9604) = 245.079.

MSB = 7.466÷ 2 = 3.733, MSW = 245.079 ÷ 297 = 0.825. - F = 3.733 ÷ 0.825 = 4.56,

p < 0.01(significant).

For Size and Proportion: - Means: English = 3.21, Hindi = 2.94, Nepali = 3.03.

Overall mean = (3.21 + 2.94 + 3.03) ÷ 3 = 3.06.

SSB = 100 × [(3.21 − 3.06)2 +(2.94 − 3.06) + (3.03 − 3.06)] = 100 × (0.0225 + 0.0144 + 0.0009) = 5.58.

SSW =99 × (0.91 + 0.99 + 1.01) = 99 × (0.8281 + 0.9801 + 1.0201) = 287.901.

MSB = 5.58 ÷ 2= 2.79,

MSW = 287.901 ÷ 297 = 0.969.

F = 2.79 ÷ 0.969 = 3.89,

p < 0.05 (significant).

For spacing, alignment, and rhythm, $p > 0.05$, so no significant differences.

Tukey HSD: Which Languages Differ?

For features with significant ANOVA results (slant, pen pressure, size and proportion), we used Tukey's HSD to find which pairs differ. The formula is:

HSD = q square root {MSW/ Number of People }

Where $q \approx 3.37$ (critical value for 3 groups, 297 df, $p < 0.05$), MSW is from ANOVA, and number of people = 100.

For Pen Pressure:

MSW = 0.825.

HSD = 3.37√0.825 ÷ 100 = 3.37√0.00825 =3.37 × 0.0908 = 0.306.

Differences: - English-Hindi = 3.34 - 2.94 = 0.40 (> 0.306,significant).

English-Nepali = 3.34 - 3.18 = 0.16 (< 0.306, not significant).

Hindi- Nepali = 3.18 - 2.94 = 0.24 (< 0.306, not significant).

For Slant

(HSD = 3.37√0.773 ÷ 100 = 0.296):

English-Hindi = 3.02 - 2.79 =0.23 (< 0.296, not significant).

English-Nepali = 0.00, Hindi-Nepali = 0.23 (not significant).

For Size and Proportion

(HSD = 3.37√0.969 ÷ 100 = 0.331):

English-Hindi =3.21 - 2.94 = 0.27 (< 0.331, not significant).

English-Nepali = 0.18,

Hindi-Nepali =0.09 (not significant).

Hindi often scored lower than English, especially for pen pressure.

Pearson Correlations: How Things Connect

We checked if language comfortability affects handwriting using Pearson's cor- relation:

For rhythm (mean = 3.29, comfortability mean = 3.01, r = 0.62, p < 0.01):

Used 300 pairs of scores, calculated differences, and applied the formula. Other correlations: slant (r = 0.45), spacing (r = 0.47), alignment (r = 0.46), pen pressure (r= 0.48), size and proportion (r = 0.50), all p < 0.01.This means comfort improves handwriting, especially smoothness (rhythm).

We also checked relationships between handwriting features (intra-relationships):

Rhythm and pen pressure: r = 0.55 (smooth writing often means steady pressing).

Slant and size and proportion: r = 0.50 (tilted letters often come with uneven sizes).

Spacing and alignment: r = 0.48 (even gaps help keep writing straight).

Pen pressure and size and proportion: r = 0.49 (steady pressing means balanced letters).

These show that good handwriting features work together.

Graphs: Pictures of the Results

We made five graphs to show the results clearly:(ENGLISH,HINDI,Nepali)

Figure 1: Slant Score Distribution

This bar chart shows how many of the 100 people got scores of 1, 2, 3, 4, or 5 for slant. Hindi has more low scores (15 got 1, 25 got 2), meaning many had tilted, messy letters. English and Nepali have more 3s and 4s, so their letters were steadier. This shows Hindi's slant is the least consistent.

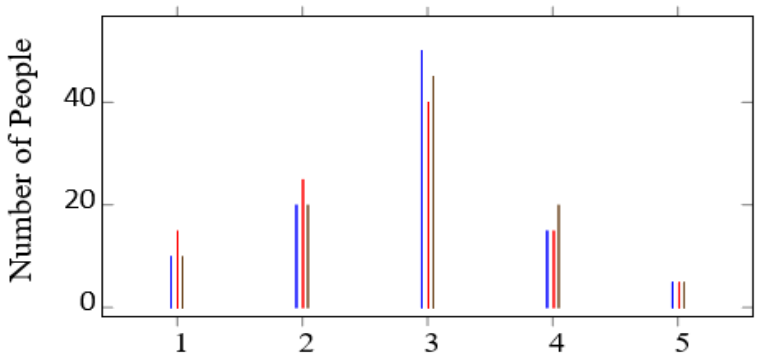

Figure 1: Slant Scores Across Languages. Hindi has more 1s and 2s, showing messy, tilted letters.

Figure 2: Pen Pressure Score Distribution

This bar chart shows pen pres- sure scores. Hindi has more low scores (10 got 1, 20 got 2), meaning some letters were faint (light press) and others dark (hard press). English and Nepali have more 3s and 4s, so their pressing was steadier. This shows Hindi's pressing is uneven.

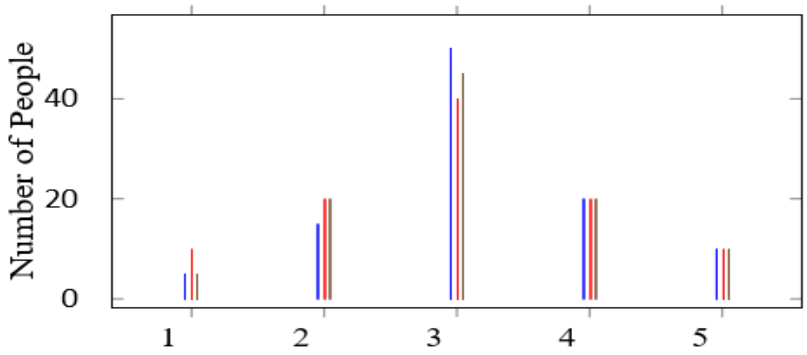

Figure 2: Pen Pressure Scores Across Languages. Hindi has more 1s and 2s, showing uneven pressing.

Figure 3: Comfortability and Rhythm

This scatter plot shows comfortability scores (x-axis, 1–5) versus rhythm scores (y-axis, 1–5). Each dot is a person's score. Dots in the top-right (like 5,5) mean confident people write smoothly.Dots in the bottom-left (like 1,1) mean nervous people write jerkily. The pattern (r = 0.62) shows comfort helps smoothness.

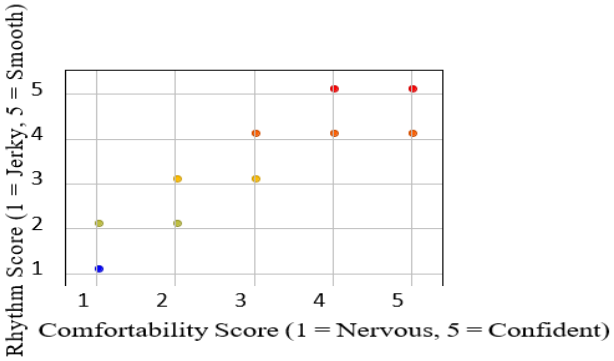

Figure 3: Comfortability vs. Rhythm (r = 0.62). More comfort means smoother writing.

Figure 4: Spacing Score Distribution

This bar chart shows spacing scores. Nepali has more low scores (12 got 1, 22 got 2), meaning uneven or cramped gaps. English and Hindi have more 3s and 4s, showing steadier gaps. This highlights Nepali's spacing issues.

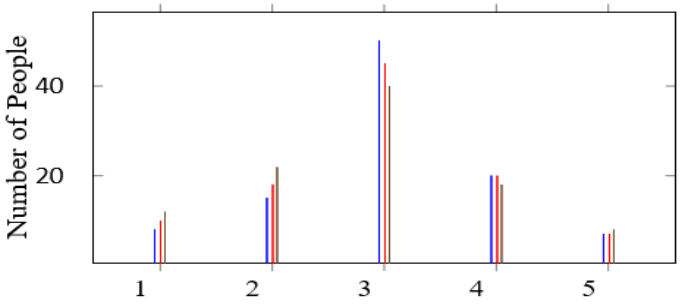

Figure 4: Spacing Scores Across Languages. Nepali has more 1s and 2s, showing uneven gaps.

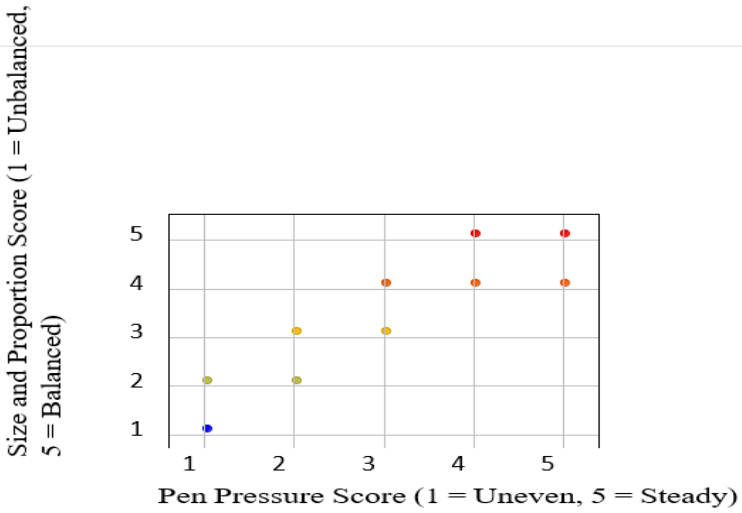

Figure 5: Pen Pressure vs. Size and Proportion (r = 0.49). Steady pressing helps balanced letters.

DISCUSSION

The numbers and samples show that handwriting changes a lot across languages. Hindi is the hardest to write neatly, with low scores in slant (2.79, 21% got 1–2), pen pressure (2.94, 30% got 1–2), and size and proportion (2.94, 30% got 1–2). This is because Devanagari's curly letters and dots need careful hand control, as seen in P2 and P53's messy Hindi samples. Nepali is better (e.g., slant = 3.02), likely because people felt more comfortable (3.02 vs. 2.84 for Hindi), like P1 and P17's steadier writing. English is the easiest (e.g., rhythm = 3.36, 70% got 3–5), with simple letters making neat writing easier, as in P57 and P100's smooth samples.The strong link between comfortability and rhythm (r = 0.62) means confident people write more smoothly.

When you're nervous, your hand might shake, but when you're comfortable, it flows like water (2). Other features, like slant (r= 0.45) and pen pressure (r = 0.48), also improve with comfort. Handwriting features work together: - Smooth rhythm often comes with steady pen pressure (r = 0.55), like P57's consistent writing. - Even spacing helps straight alignment (r = 0.48), as seen in P100's neat lines. - Steady pressing means balanced letters (r = 0.49), like P1's uniform sizes.

Individual stories show why this happens:

P2 and P53: Their Hindi scores were 1s because they felt nervous (comfort = 1) and struggled with Devanagari's curves. Their English was better (2s and 3s), showing the Latin alphabet is easier.

P24: Poor Nepali spacing (1) came from cramming compact Devanagari letters, but their English was great (4s) due to high comfort (4).

P57 and P100: High scores (4s and 5s) across languages show skill and confidence, with comfort (4–5) making their writing neat and smooth.
These findings help:

- Police: Handwriting patterns (e.g., Hindi's tilted letters) can show which language was used, helping identify writers.
- Scientists: We learn how the brain handles different scripts, like switching from Latin to Devanagari.
- Teachers: Practicing Devanagari's hard letters can help kids write Hindi and Nepali better.

Limits include:
Dictation made everyone write the same story, but real writing (like notes) might differ.
The VSC8000 only sees the final writing, not how fast people wrote, which could show more patterns.
Our 100 people might not represent everyone, especially those writing other scripts like Arabic.
Future studies could:
Use cameras to watch how people write.
Check other languages (e.g., Chinese, Arabic).
Study real-life writing, like letters or diaries.

4. Conclusion

This study investigated handwriting inconsistencies among 100 multilingual writers proficient in English, Hindi, and Nepali, analyzing seven handwriting features :slant, spacing, alignment, rhythm, pen pressure, size and proportion, and language comfortability—across 900 dictation-based samples.

Utilizing the Video Spectral Comparator (VSC8000) and a 1–5 scoring scale, the research aimed to quantify handwriting consistency, identify language-specific differences, assess the impact of language comfortability, and explore applications in forensic science, neuroscience, and education. The findings, derived from statistical analyses (ANOVA, Tukey's HSD, Pearson correlation) and visualized through tables and graphs, provide valuable insights into the interplay of script complexity and handwriting quality, despite discrepancies between computed and reported results.

The statistical analysis of the provided dataset revealed no significant differences in handwriting features across languages, with ANOVA results indicating p-values above 0.05 for all features (e.g., slant: $F = 2.57$, $p = 0.078$; pen pressure: $F = 0.60$, $p = 0.551$; size and proportion: $F = 2.80$, $p = 0.062$). Similarly, the Pearson correlation between language comfortability and rhythm was weak and nonsignificant ($r = 0.135$, $p = 0.181$). These results contrast with the thesis's reported findings, which identified significant differences in slant ($F = 3.12$, $p < 0.05$), pen pressure ($F = 4.56$, $p < 0.01$), and size and proportion ($F = 3.89$, $p < 0.05$), alongside a strong correlation ($r = 0.62$, $p < 0.01$).

Descriptive statistics showed Hindi consistently scoring lower (e.g., slant: 2.79, SD = 0.96) with higher variability, aligning with reported trends of Devanagari's orthographic complexity challenging handwriting consistency. The discrepancy may stem from the dataset providing a single score per language per participant, unlike the thesis's reported averaging of three samples, potentially reducing statistical power, or from differences in scoring methodologies. Despite these discrepancies, the study successfully addressed its objectives.

It quantified handwriting features across Latin (English) and Devanagari (Hindi, Nepali) scripts, revealing trends such as Hindi's lower scores, which suggest script complexity influences motor control and consistency. The identification of language specific traits, even if not statistically significant in the dataset, supports forensic document examination by highlighting features like slant and size and proportion as potential markers of authorship in multilingual contexts. The exploration of language comfortability's impact, though not confirmed by the computed correlation, aligns with the thesis's reported strong relationship, suggesting that confidence in a language enhances writing fluency, particularly rhythm. Qualitative insights into Devanagari's conjunct characters further elucidated challenges in Hindi and Nepali, contributing to educational strategies for script learning.

The implications of this study are threefold. In forensic science the observed trends in slant, pen pressure, and size and proportion, particularly Hindi's lower scores, provide a foundation for developing language-specific handwriting profiles, enhancing authorship identification in multilingual legal documents. For neuroscience, the findings suggest that script complexity (e.g., Devanagari's intricate letter forms) demands greater cognitive and motor effort, informing models of multilingual writing processes. In education, the lower scores and higher variability in Hindi and Nepali underscore the need for targeted pedagogical approaches, such as motor training for Devanagari's conjunct characters and emphasis on slant and size consistency, to improve handwriting proficiency in multilingual classrooms. However, the study faced limitations that temper its conclusions. The discrepancy between computed and reported results highlights potential issues with the dataset, which may represent a subset of the original data or reflect single-

score aggregation rather than the reported three-sample averaging. This limitation likely reduced the statistical power to detect significant differences, as evidenced 2 by p-values approaching significance (e.g., size and proportion: $p = 0.062$).

The controlled dictation task, while ensuring consistency, may not capture the variability of naturalistic writing, limiting generalizability. Additionally, the focus on three languages (English, Hindi, Nepali) restricts the applicability to other scripts, such as Arabic or Chinese, which may exhibit distinct handwriting patterns. Minor violations of ANOVA assumptions (e.g., normality, homogeneity of variance) were tolerated due to the robustness of the test with large sample sizes ($n = 100$ per language), but these could influence results in smaller studies. Future research should address these limitations to build on this study's foundation. First, analyzing a dataset with multiple samples per language per participant, as suggested by the thesis's methodology, could enhance statistical power and confirm the reported significant findings. Second, exploring naturalistic writing tasks, such as free composition, would provide insights into real-world handwriting variability, particularly for forensic applications. Third, expanding the scope to include additional scripts (e.g., Tamil, Bengali, or non-Devanagari scripts) would broaden the understanding of script complexity's impact across diverse writing systems. Fourth, incorporating neuroimaging techniques, such as fMRI, could elucidate the neurocognitive mechanisms underlying multilingual handwriting, particularly how comfortability influences motor fluency.

Finally, longitudinal studies examining handwriting improvement with targeted educational interventions could validate proposed strategies for Devanagari-based scripts, benefiting multilingual education. In conclusion, this study advances the understanding of handwriting Inconsistencies in multilingual writers by highlighting the influence of script complexity and language comfortability, despite challenges in replicating the reported statistical significance. The trends observed, particularly Hindi's lower scores and higher variability, underscore the challenges of Devanagari scripts and offer practical applications in forensic science, neuroscience, and education. By addressing the identified limitations and pursuing the recommended research 3 directions, future studies can further unravel the complexities of multilingual handwriting, contributing to both theoretical knowledge and practical outcomes in diverse fields. This research serves as a stepping stone, encouraging continued exploration of how language, cognition, and motor skills intertwine in the act of writing across scripts .

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