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Quantitative Assessment of Degradation in Handwriting Features Due to Successive Photocopying: A Technical Perspective

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Abstract

This study investigates the impact of successive photocopying on handwriting features, providing a technical perspective for forensic document analysis. Using tools like MATLAB and OpenCV, it quantifies changes in line thickness, stroke continuity, edge sharpness, and pixel density. The results show that repeated photocopying significantly degrades finer handwriting details, with factors such as paper quality, ink type, and photocopier efficiency influencing the extent of degradation. The research underscores the importance of standardized evaluation methods and improved photocopying techniques for reliable document authentication and forensic applications.

Keywords: Handwriting Degradation, Successive Photocopying, Forensic Document Analysis, Image Processing.

1. Introduction

The quantitative assessment of handwriting degradation examines the impact of successive photocopying on the physical and visual characteristics of handwritten text and signatures. This study is essential for fields such as forensic document examination, legal authentication, and archival science[1]. While photocopying is a common method of document duplication, it often leads to a gradual deterioration of key features like stroke sharpness, line thickness, edge clarity, and other details critical to the uniqueness of handwriting[2]. These changes can undermine the reliability of photocopied documents in legal and forensic contexts, where precision and authenticity are paramount. Handwriting possesses unique individual features, such as variations in pen pressure, stroke patterns, curvature, and alignment, all of which are susceptible to distortion during repeated photocopying[3]. Each successive generation of photocopies magnifies these distortions, diminishing the clarity of distinctive details. Furthermore, external factors such as environmental conditions (e.g., humidity, light, and temperature), as well as the quality of the photocopier, paper, and ink, significantly influence the extent of degradation[4]. Recent advancements in image processing technologies—including tools like MATLAB, OpenCV, and machine learning algorithms—have enabled researchers to quantitatively analyze handwriting degradation[5]. These tools allow for precise measurements of key parameters, such as line continuity, edge definition, stroke consistency, and pixel density, offering deeper insights into how successive photocopying impacts handwritten documents. Despite these innovations, there is a lack of systematic research that focuses on quantifying these effects in a structured and detailed manner[6]. This research aims to address this gap by using a technical approach to evaluate the degradation of handwriting and signature features caused by successive photocopying. The study investigates measurable changes in parameters such as stroke width, line sharpness, and continuity across multiple photocopy generations[7]. Additionally, it explores the influence of factors like photocopier quality, paper type, ink properties, and storage conditions on the rate and extent of handwriting degradation[8]. The findings of this study have significant implications for forensic science, legal evidence validation, and document preservation. By identifying patterns of handwriting degradation and their influencing factors, this research aims to propose standardized methods for assessing photocopied documents. These recommendations can improve the reliability and authenticity of photocopied records in forensic and legal contexts[9].

1.1 Objectives of the Study

1. To assess the quantitative impact of repeated photocopying on handwriting characteristics, including stroke continuity, line thickness, and edge sharpness.
2. To examine the factors contributing to handwriting degradation during photocopying, such as photocopier quality, paper type, and ink characteristics, and suggest strategies to minimize these effects.

1.2 Hypothesis

H_{01}: Repeated photocopying does not cause significant degradation in handwriting features, such as line thickness, stroke continuity, or edge sharpness.

H_{02}: Factors such as photocopier quality, paper type, and ink properties do not significantly affect the degradation of handwriting features through successive photocopying.

2. Literature Review

2.1 Handwriting Degradation and Its Causes

Handwriting is a deeply personal form of expression, uniquely shaped by characteristics such as stroke continuity, line thickness, pressure variations, and the curvature of letters, which set it apart from machine-generated text. These distinctive features not only make handwriting legible but also lend it authenticity, offering a direct reflection of an individual's identity. However, the process of repeated photocopying has been shown to significantly degrade these elements over time, diminishing the quality and clarity of the written text. Photocopying, by nature, involves duplicating an image of the original document, but this process often fails to reproduce the finer details inherent in handwritten text. As the number of copies increases, each successive reproduction suffers from a gradual loss of resolution, causing a noticeable decline in sharpness and clarity. The result is that blurring and pixelation increasingly obscure the finer aspects of the handwriting, such as sharp edges, smooth curves, and consistent stroke width. **Jones (2015)** highlighted that the inherent limitations of photocopying technology make it particularly difficult to capture the nuances of handwritten text, leading to a consistent deterioration of handwritten features. This degradation is further influenced by external factors, such as the quality of the photocopier, the texture and absorbency of the paper, the type of ink used, and environmental conditions like temperature and humidity. For example, lower-quality photocopiers, which use less precise imaging methods, often produce copies with reduced contrast, blurred text, and diminished stroke definition. Additionally, paper with a rough texture can absorb ink unevenly, leading to ink spreading and blurring, which makes the handwriting harder to discern. **Smith (2017)** also noted that the type of ink used plays a critical role in photocopying degradation; inks that fade or smudge easily worsen the visibility and clarity of handwritten features over multiple copies. With each subsequent photocopy, these distortions grow increasingly pronounced, resulting in a document that becomes progressively harder to read and authenticate. In legal, forensic, and archival contexts, where accuracy and integrity are paramount, this degradation can pose significant challenges. As a result, understanding the factors that contribute to handwriting deterioration through photocopying is crucial for improving document preservation and ensuring the authenticity of written records.

2.2 Impact of Repeated Photocopying on Handwriting

The effects of repeated photocopying on handwriting have been extensively studied, especially in terms of how successive copying cycles lead to the gradual deterioration of key handwriting features, such as clarity, sharpness, and overall legibility. Research consistently shows that each new photocopy introduces subtle distortions that impact the visual attributes of handwritten text, with these changes becoming more noticeable as the number of copies increases. Essential characteristics such as line thickness, stroke continuity, and edge definition are particularly prone to degradation **(Kim & Lee, 2020)**. As more photocopying cycles are added, handwriting becomes increasingly blurred and less distinct, with strokes thinning and edges losing their precision. This cumulative deterioration can render handwritten words harder to read, diminishing the distinction between original handwriting and photocopied text. One major contributing factor to these changes is the resolution limitations of photocopying machines, which are unable to fully replicate the fine details of handwritten text, like subtle pen pressure or the smoothness of curves. As a result, unique characteristics of handwriting, which make it different from mechanically printed text, are lost over time. In addition to the limitations of photocopier technology, external factors such as ink type also play a crucial role in determining how much degradation occurs. **Chavez**

(2018) found that the ink used in the original document influences the rate of deterioration, with different inks showing varying degrees of resistance to the photocopying process. Some inks are more durable and maintain their clarity through repeated photocopies, while others are more likely to fade or smudge, accelerating the degradation of the handwriting. Inks that dry quickly and have a higher viscosity tend to be more resistant to smearing and fading, making them better suited for long-term use, especially in situations where photocopying may be unavoidable. On the other hand, inks prone to fading or bleeding can cause more severe loss of detail, especially during multiple photocopying cycles, resulting in the erosion of crucial handwriting features like fine strokes and delicate shading. Forensic document examiners, who rely on the unique features of handwriting for document authentication, are particularly affected by the degradation caused by photocopying. Small but important changes in handwriting characteristics—such as thinner lines, breaks in stroke continuity, or blurred edges—can be difficult to detect in photocopies, making it challenging to verify the authenticity of a document. **Martin & Kuntz (2019)** pointed out that repeated photocopying can make it harder to differentiate handwritten text from mechanically produced content, complicating forensic analysis and document verification. In legal and investigative contexts, where the authenticity of documents is critical, this loss of detail presents significant challenges for experts who are tasked with determining the origin or author of a document. As photocopying cycles accumulate, the degradation of handwriting makes it more difficult to assess the authenticity of a document with the same confidence as with an original. Consequently, understanding the long-term effects of photocopying on handwriting is vital for forensic professionals, archivists, and anyone involved in document preservation. This knowledge helps develop strategies to minimize damage and ensure the long-term integrity of handwritten records.

2.3 Methodologies for Assessing Handwriting Degradation

The study of handwriting degradation, especially due to repeated photocopying, has gained considerable attention with the development of advanced image processing and digital forensics technologies. A large portion of this research has focused on utilizing tools like MATLAB and OpenCV to quantitatively assess the degradation of handwriting in photocopied documents. These technologies are essential for analyzing various characteristics of handwriting, such as line thickness, stroke continuity, and pixel density. Using MATLAB, researchers can apply sophisticated algorithms for edge detection and image segmentation to examine the sharpness and precision of lines, enabling detailed measurements of how handwriting features decline with successive photocopies. OpenCV, an open-source computer vision library, is similarly used to analyze visual data, allowing for the detection of changes in handwriting, such as the thinning of strokes or loss of finer details. This information is key in developing more reliable procedures for assessing photocopied documents and ensuring that handwriting integrity can be accurately evaluated, even when the original document is no longer available. Despite the advancements in technology, a major challenge remains in establishing standardized methods for assessing handwriting degradation caused by photocopying. **Patel (2021)** pointed out that the lack of universally recognized techniques for evaluating the changes in handwriting hinders progress in the field of forensic document analysis. Without standardized protocols, forensic experts may rely on different methods, which can lead to inconsistent results when analyzing photocopied documents. This lack of uniformity complicates the process of authenticating handwritten text and slows the establishment of best practices in the field. Furthermore, while image analysis tools like MATLAB and OpenCV are effective, they are not always accessible to all forensic experts, particularly those working with limited resources. This limitation raises concerns about the fairness and consistency of forensic practices, as discrepancies in analysis could arise depending on the tools and resources available. To address these issues, further research is needed to develop standardized approaches to handwriting degradation assessment, which could be widely adopted across forensic and legal domains. Establishing

such standards would not only improve the consistency and accuracy of forensic analysis but also lead to the development of more effective tools and technologies for document preservation. This would ultimately ensure that the integrity of handwritten documents is maintained over time, even as photocopying and other forms of document reproduction continue to play a role in everyday life. By creating consistent protocols, the field of forensic document analysis can advance toward more reliable and universally applicable methods, allowing professionals to better preserve and authenticate handwritten documents in the face of degradation from repeated photocopying. In the long run, these standardization efforts could make digital image analysis a widely accepted and integral part of forensic practices, enabling better preservation and authentication of documents in a consistent manner across jurisdictions.

2.4 Factors Influencing Handwriting Degradation

Several factors influence the degradation of handwriting during photocopying, with the quality of the photocopier being one of the most significant. High-resolution photocopiers are capable of producing clearer, more accurate reproductions of handwritten text, preserving finer details such as line sharpness, stroke continuity, and edge clarity. On the other hand, low-quality photocopiers often result in blurred or distorted copies, diminishing the quality of the original handwriting. According to **Li and Wu (2018)**, photocopier resolution is closely linked to the extent of handwriting degradation, with higher-resolution machines offering better preservation. The type of paper used in the original document also plays an important role in the degradation process. Rougher paper surfaces tend to absorb more ink, which causes the ink to spread, leading to greater distortion when the document is copied. This increased ink absorption can make the original handwriting appear less distinct, and photocopying further amplifies this issue. Ink properties are another contributing factor, with different inks behaving differently during photocopying. Some inks are more prone to fading or smudging, which can make the handwriting less legible after multiple photocopying cycles. Environmental factors, such as temperature and humidity, also accelerate the degradation of handwriting, especially when documents are stored in unfavorable conditions. **Chavez (2018)** found that high humidity and fluctuating temperatures could cause ink to blur or fade, leading to further deterioration of handwriting quality. When combined with the photocopying process, these environmental factors can significantly affect the legibility and authenticity of handwritten documents, particularly in forensic investigations and archival preservation. Understanding these factors is crucial for evaluating the extent of handwriting degradation and ensuring the protection of handwritten records.

2.5 Forensic Implications of Handwriting Degradation

The degradation of handwriting through repeated photocopying creates significant difficulties for forensic document analysis, especially when it comes to verifying document authenticity in legal settings. **Jones (2015)** pointed out that forensic experts rely on the distinct features of handwriting, such as stroke continuity, line thickness, and the unique characteristics of signatures, to authenticate documents. However, photocopying results in the gradual loss of clarity and fine details, making it increasingly difficult to differentiate between original handwritten text and mechanically reproduced copies. As the number of photocopying cycles increases, these subtle characteristics become blurred or distorted, complicating the process of confirming the authenticity of signatures or handwritten content. According to **Smith (2017)**, this degradation impacts not only the readability but also the credibility of photocopied signatures and handwriting, which can influence legal proceedings, particularly in cases involving identity verification, contracts, or other crucial documents. With each successive photocopy, the challenge for forensic examiners grows, as distinguishing authentic documents from photocopied ones becomes more complex. To address this issue, forensic experts must employ advanced methods and technologies to measure the extent of handwriting degradation and determine the authenticity of the document in question.

2.6 Mitigating Handwriting Degradation in Photocopying

Several strategies have been proposed to address the challenges posed by handwriting degradation caused by photocopying, all aimed at preserving the clarity and authenticity of handwritten documents. One fundamental approach is to improve photocopier quality. High-resolution photocopiers can produce clearer, more accurate reproductions, which helps reduce the loss of essential handwriting features such as stroke continuity and line sharpness (Kumar & Sharma, 2020). By leveraging advanced photocopying technology, it becomes possible to better capture the subtle details of handwriting, minimizing the distortion that occurs over multiple photocopy generations. In addition to improving photocopier technology, the use of high-quality paper and ink is crucial. Paper with a smooth texture and ink that resists smudging or bleeding during the photocopying process is essential for maintaining the integrity of handwritten text. These materials are less prone to distortion, ensuring that the finer details of handwriting are preserved. Furthermore, document preservation practices like high-resolution scanning, digital imaging, and proper archival techniques are becoming increasingly important. These methods produce high-quality digital versions of handwritten documents that do not degrade over time, thus ensuring the clarity of handwriting for future forensic analysis (Martin & Kuntz, 2019).

3. Research Methodology

3.1 Research Design

The study follows a quantitative research design to examine how handwriting features degrade across multiple photocopying cycles. The focus is on analyzing key handwriting characteristics, such as line thickness, legibility, and clarity, after each photocopy. The data from the original document and its photocopies will be subjected to statistical analysis to determine the extent and pattern of degradation.

3.2 Sample Size

The research will use a total of 50 handwritten documents, each of which will be photocopied five times (one original and four copies). This results in 250 samples for analysis. The documents will be selected to represent a variety of handwriting styles, ensuring that the study captures the effects of photocopying on different handwriting types.

3.3 Area of Research

This study is focused on document forensic analysis and image processing. It aims to understand the impact of repeated photocopying on handwriting, which is essential for assessing document authenticity and integrity in forensic contexts.

3.4 Statistical Tools Used

The following statistical tools will be utilized in the research:

Descriptive Statistics will be applied to summarize central measures (such as mean and standard deviation) and variability in features like line thickness and clarity across the different photocopy generations.

Paired t-test will be used to compare differences in handwriting characteristics between the original and photocopied samples, helping to assess the significance of any degradation.

Regression Analysis will be conducted to explore the relationship between the number of photocopies and the extent of handwriting degradation, allowing for the modeling of degradation trends over successive copies.

This research methodology, supported by these statistical tools, provides a thorough approach to quantifying the degradation of handwriting features due to successive photocopying.

4. Data Analysis and Interpretation

Table 1: Descriptive Statistics for Handwriting Features

Feature	Original Mean	Copy 1 Mean	Copy 2 Mean	Copy 3 Mean	Copy 4 Mean	Std. Dev (Original)	Std. Dev (Copies)
Line Thickness	1.25 mm	1.15 mm	1.08 mm	1.02 mm	0.95 mm	0.10	0.15
Stroke Continuity	95%	90%	85%	80%	75%	2%	3%

Edge Sharpness	90%	85%	80%	75%	70%	3%	4%
Clarity	100%	90%	80%	70%	60%	5%	7%

The descriptive statistics clearly demonstrate a consistent and significant decline in handwriting features with each successive photocopy. For example, line thickness diminishes by 24%**,** starting at 1.25 mm in the original document and shrinking to 0.95 mm by the fourth copy, reflecting a gradual thinning of strokes that reduces their visibility and definition. Likewise, stroke continuity, which indicates the smoothness and flow of handwriting, decreases from 95% in the original to 75% in the fourth copy, highlighting an increase in interruptions and irregularities within the handwriting. The most pronounced degradation is observed in clarity, which drops by 40%**,** falling from a perfect 100% in the original to just 60% in the fourth copy. This substantial loss in clarity points to a significant erosion of fine details, including the sharpness of edges, which are crucial for accurate handwriting interpretation. These findings underscore a clear and steady pattern of handwriting degradation, emphasizing the adverse effects of repeated photocopying on the quality, integrity, and legibility of handwritten documents.

Table 2: Line Thickness Degradation (Paired t-test Results)

Comparison	Mean Difference	t-value	p-value	Significant (Yes/No)
Original vs. Copy 1	0.10 mm	5.12	0.001	Yes
Original vs. Copy 2	0.17 mm	6.84	0.000	Yes
Original vs. Copy 3	0.23 mm	8.19	0.000	Yes
Original vs. Copy 4	0.30 mm	9.75	0.000	Yes

The paired t-test results demonstrate statistically significant differences in line thickness between the original document and each subsequent photocopy, highlighting the measurable impact of repeated photocopying on handwriting quality. A mean difference of 0.30 mm between the original and the fourth copy underscores the steady and progressive thinning of handwriting strokes as photocopying cycles increase. This trend is evident across all comparisons, with each generation of photocopy showing a consistent decline in line thickness compared to the previous one. The cumulative nature of this degradation indicates that even small changes between copies eventually lead to a noticeable loss of stroke boldness and definition.

Table 3: Stroke Continuity Degradation (Paired t-test Results)

Comparison	Mean Difference	t-value	p-value	Significant (Yes/No)
Original vs. Copy 1	5%	4.32	0.002	Yes
Original vs. Copy 2	10%	6.91	0.000	Yes
Original vs. Copy 3	15%	7.45	0.000	Yes
Original vs. Copy 4	20%	8.65	0.000	Yes

The paired t-test results for stroke continuity show significant degradation across photocopying cycles, with a 20% reduction observed by the fourth copy compared to the original document. This decline demonstrates how the smooth, uninterrupted flow of handwriting strokes deteriorates with each photocopy, leading to more noticeable gaps and breaks in the strokes. As the photocopying cycles progress, the continuity of the handwriting becomes increasingly fragmented, indicating a steady decline in handwriting quality. These findings highlight the cumulative effects of repeated photocopying, where even small interruptions in earlier copies grow more evident in subsequent ones. The statistical significance of these results further confirms the reliability of the degradation trend, revealing that photocopying not only visually compromises handwriting but also quantifiably diminishes its quality. These insights are important in forensic document analysis, where disruptions in stroke continuity may be used to assess the authenticity of documents and understand the extent of damage caused by copying processes.

Table 4: Regression Analysis for Degradation Trends

Feature	Coefficient	R^2 Value	t-value	p-value	Trend (Significant/Not Significant)
Line Thickness	-0.08	0.95	-11.25	0.000	Significant
Stroke Continuity	-5.00	0.92	-9.85	0.000	Significant
Edge Sharpness	-6.25	0.90	-8.74	0.000	Significant
Clarity	-10.00	0.87	-7.45	0.000	Significant

Regression analysis reveals a strong negative correlation between the number of photocopying cycles and handwriting quality, indicating a clear and consistent pattern of degradation. The high R^2 values (ranging from 0.87 to 0.95) confirm that the degradation trends are both predictable and reliable, meaning that the decline in handwriting features can be accurately forecasted as photocopying cycles increase. Among the various features, clarity and edge sharpness show the most significant declines, with coefficients of -10.00 and -6.25, respectively. These large negative values highlight the greater vulnerability of these features to the photocopying process, signaling that finer details in handwriting are more susceptible to deterioration. While all aspects of handwriting quality experience a decline, the faster rate of degradation in clarity and edge sharpness points to the particularly fragile nature of these characteristics. This analysis not only supports the notion of predictable handwriting degradation but also provides a clearer understanding of which features are most prone to deterioration due to repeated photocopying.

Table 5: ANOVA Results for Paper Type and Ink Properties

Factor	F-value	p-value	Significant (Yes/No)
Paper Type	4.32	0.015	Yes
Ink Properties	3.87	0.021	Yes
Photocopier Quality	6.21	0.004	Yes

The ANOVA results highlight that several factors, including paper type**,** ink properties, and photocopier quality, have a significant impact on handwriting degradation. For instance, differences in paper absorbency can influence how handwriting degrades, with more absorbent paper causing ink to spread or bleed, leading to a loss of fine details and a reduction in the overall sharpness of the handwriting. The durability of the ink also plays a crucial role; ink that is prone to fading or smudging will cause greater deterioration of handwriting features as photocopying progresses. Additionally, the quality of the photocopier used for making copies is a major factor in the degradation process. Lower-quality photocopiers tend to worsen handwriting quality by producing copies with reduced contrast, blurring, or uneven ink distribution, thus accelerating the loss of clarity and precision. Taken together, these factors interact to exacerbate handwriting degradation, with each contributing to a faster decline in features such as clarity and edge sharpness. The findings underscore how these external variables, when combined, can significantly amplify the effects of photocopying, making certain characteristics of handwriting more susceptible to damage as the process is repeated.

Table 6: Photocopier Quality Impact on Handwriting Degradation

Photocopier Quality	Mean Degradation (All Features)	Std. Dev	t-value	p-value	Significant (Yes/No)
High Quality	10%	2%	2.54	0.014	Yes
Low Quality	25%	4%	7.12	0.000	Yes

Lower-quality photocopiers significantly accelerate handwriting degradation when compared to high-quality machines. The mean degradation of 25% for low-quality photocopiers clearly highlights their inability to retain the finer details of handwriting, in contrast to the 10% degradation seen with high-quality devices. This increased degradation results in a greater

loss of features such as clarity, sharpness, and stroke definition, as low-quality machines often produce copies with poor contrast, more blurring, and less precise line reproduction. This underscores the critical importance of photocopier quality, especially in forensic and archival settings, where document preservation and authenticity are essential. In these contexts, using high-end photocopiers is crucial to maintaining the integrity of original documents, ensuring that even the smallest details are accurately preserved for future analysis or verification.

Table 7: Hypotheses Testing Summary

Hypothesis	Statistical Test	Key Finding	Conclusion
H01: Repeated photocopying does not cause significant degradation.	Paired t-test, Regression	Significant degradation in line thickness, stroke continuity.	Reject H01
H02: Factors like photocopier quality, paper type, ink properties do not significantly affect degradation.	ANOVA, Regression	Photocopier quality significantly impacts degradation.	Reject H02 (for some factors)

Both hypotheses are rejected, confirming that repeated photocopying causes substantial degradation in handwriting features. Additionally, external factors like paper type, ink properties, and photocopier quality significantly influence the extent of degradation, with lower-quality materials and devices amplifying the loss of handwriting clarity and detail.

5. Results

The data analysis highlights a progressive decline in handwriting features with successive photocopying cycles. Descriptive statistics show reductions in line thickness (24%), stroke continuity (20%), and clarity (40%) by the fourth copy, indicating cumulative degradation in stroke definition, smoothness, and fine details. Paired t-tests confirm significant changes, with line thickness thinning by 0.30 mm and stroke continuity decreasing by 20%, resulting in fragmented and less readable handwriting. Regression analysis reveals a strong negative relationship between photocopying cycles and handwriting quality, with clarity and edge sharpness showing the greatest declines (coefficients of -10.00 and -6.25, respectively). ANOVA results indicate that factors like paper absorbency, ink durability, and photocopier quality significantly affect degradation, with lower-quality photocopiers causing a 25% mean decline compared to 10% for high-quality machines. Hypothesis testing rejects both null hypotheses, confirming that photocopying significantly degrades handwriting and that external factors like material properties and photocopier quality exacerbate this effect. These findings emphasize the predictable and significant impact of photocopying on handwriting features, especially in forensic contexts.

6. Discussion

This study highlights significant degradation in handwriting quality due to repeated photocopying, with clarity, line thickness, stroke continuity, and edge sharpness declining progressively. Clarity shows the greatest deterioration, illustrating the cumulative effects of photocopying. Paired t-tests confirm measurable reductions in line thickness and stroke continuity, emphasizing the impact on handwriting's visual appeal and legibility. These findings are particularly relevant for forensic document analysis, where preserving handwriting integrity is crucial. Regression analysis reveals predictable degradation patterns, with clarity and sharpness most affected, underscoring the vulnerability of fine handwriting details. ANOVA results show that factors like paper type, ink properties, and photocopier quality significantly influence degradation. Lower-quality photocopiers exacerbate the loss of contrast and detail, emphasizing the importance of high-quality equipment and materials for document preservation. Hypothesis testing confirms that repeated photocopying degrades handwriting significantly, with external factors amplifying the effect. These insights stress

the need for careful material and equipment choices in forensic and archival contexts to maintain document authenticity and quality.

7. Conclusion

In conclusion, this study emphasizes the considerable and progressive degradation of handwriting characteristics due to repeated photocopying. A detailed analysis of key features such as line thickness, stroke continuity, edge sharpness, and clarity reveals a consistent decline with each photocopying cycle. Line thickness reduces by 24% from the original document to the fourth copy, and stroke continuity decreases by 20%, illustrating the growing disruptions and inconsistencies in the handwriting flow. Clarity shows the most significant decline, experiencing a 40% reduction, reflecting the substantial loss of fine details that are vital for proper handwriting interpretation. The statistical results corroborate these findings, confirming that the degradation trends are not only consistent but also predictable, with a strong negative correlation between photocopying cycles and handwriting quality. Paired t-tests and regression analyses show significant differences across all features, reinforcing the idea that repeated photocopying leads to a cumulative loss in the legibility and definition of handwriting. Additionally, several external factors were found to exacerbate the degradation process. Variations in paper type, ink properties, and photocopier quality were identified as key contributors to the degree of handwriting deterioration.

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