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PAPER

QUESTIONED DOCUMENTS

Linton A. Mohammed,[1,2] M.F.S.; Bryan Found,[2,3] Ph.D.; Michael Caligiuri,[4] Ph.D.; and Doug Rogers,[2] Ph.D.

The Dynamic Character of Disguise Behavior for Text-based, Mixed, and Stylized Signatures

ABSTRACT: The aims of this study were to determine if dynamic parameters (duration, size, velocity, jerk, and pen pressure) differed for signing style (text-based, stylized, and mixed) and if signing style influences handwriting dynamics equally across three signature conditions (genuine, disguised, and auto-simulation). Ninety writers provided 10 genuine signatures, five disguised signatures, and five auto-simulated signatures. All 1800 signatures were collected using a digitizing tablet resulting in a database of each signature's dynamic characteristics. With genuine signatures, there were significant differences between styles for size, velocity, and pen pressure, and there were significant differences between genuine signatures and at least one of the un-natural signature conditions for all parameters. For velocity and size, these changes with condition were dependent on style. Changes with condition for the other parameters were similar for the three styles. This study shows that there are differences among natural signature styles and disguise behaviors that may be relevant in forensic signature examinations.

KEYWORDS: forensic science, document examination, signature examination, signature style, dynamic parameters, disguise, auto-simulation

The examination and comparison of signatures comprise a large proportion of the casework of most Forensic Document Examiners (FDEs). In typical case scenarios, the questioned or disputed signatures that FDEs examine are genuine, disguised, or simulated. The FDE is required to apply his or her knowledge, skills, and abilities acquired through appropriate education, training, and experience to extract features from signature forms and make a determination as to which of these signature types any given questioned signature is likely to be.

There exists a large body of work on forensic signature examination method and techniques (1–6). The vast majority of research regarding signatures in the forensic environment has focused on static traces. Visually detectable features have been described which are thought to provide predictors which indicate to the FDE whether questioned signatures are genuine, disguised, or forged (7–13). Research into static features associated with different signing behaviors has been supplemented by dynamic studies where dynamic data, such as pen pressure, stroke formation velocities, and movement durations, are collected as subjects wrote their signatures on digitizing pads. This technique has been used to report on the dynamic effects of disguise and simulation behaviors (14). Empirical data emerging from both static and dynamic signature research continue to provide FDEs with a resource on which to underpin their opinions in the casework environment.

FDEs using traditional subjective techniques have consistently been shown to outperform laypersons in determining the authenticity of signatures (15,16). However, a recent report indicates that FDEs may have difficulty discriminating between signatures that are disguised and those that are forged (17). This serves as a focus of the research reported here. Of particular interest is the disguised group of signing behaviors. Disguise strategies are enacted by individuals who wish to produce signatures they intend to deny at a later point in time. Not surprisingly, the circumstances under which individuals are signing can affect the strategy that they adopt. A "free-form" disguise strategy may be used when the recipient of the document is unlikely to know what the signer's real signature looks like. Under these circumstances, the signer is free to produce a form which may be totally different to their normal signature. Clearly, this technique is unlikely to be effective should the recipient of the signature have a specimen (exemplar) of the signer's normal signature for side-by-side comparison (as in a bank). Under these circumstances, the signer has to design a signature that is close enough to the genuine form to pass inspection, but must include feature(s) that can later be used as evidence of forgery. This type of disguised signature, which may display features found in actual forgeries, is often referred to as an auto-forgery (9,18). Because the term *forgery* has legal implications, for the purposes of this paper we will refer to this category of disguised signatures as an *auto-simulation*.

It should be noted that genuine signatures can be considered to be natural writings of a person while disguised or auto-simulated signatures can be considered to be unnatural signatures of the same person.

When considering any study of signature disguise strategies, the design of the normal signature must be taken into account, as it

[1]San Diego Sheriff's Regional Crime Laboratory, 5255 Mt. Etna Drive, San Diego, CA 92117.
[2]Handwriting Analysis and Research Laboratory, School of Human Biosciences, La Trobe University, Bundoora, Vic. 3086, Australia.
[3]Document Examination Unit, Digital and Documents Evidence Branch, Victoria Police Forensic Services Department, Macleod, Vic. 3085, Australia.
[4]Department of Psychiatry, School of Medicine, University of California, San Diego, San Diego, CA 92037.

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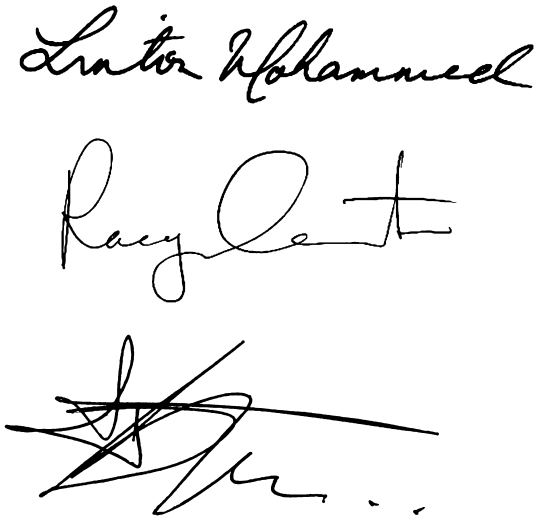

FIG. 1—*Classification of signatures into three styles: text-based (upper), mixed (middle), and stylized (lower).*

may impact on the disguise approach adopted by the writer. One element of signature design, which is relatively straightforward to classify, is the extent of stylization in the form. Fluently written signatures can be divided into three subtypes: "text-based" (where all of the allographs are legible), "mixed" (where one or more, but not all, of the allographs are legible), and "stylized" (where none of the allographs are legible). Examples of these three signatures styles are provided in Fig. 1. The frequency of occurrence of these three styles in signatures produced by a group of writers from San Diego County has been reported in the literature (19).

Previous research has shown that common disguise strategies include changing the formation of capital letters, changing the slant, and changing the speed of writing (7–11). This research does not indicate if writers of mixed, stylized, and text-based signatures employ the same or different disguise strategies.

The aim of this study is to determine if signing style (text-based, mixed, and stylized) influences handwriting dynamics equally across three signature conditions (genuine, disguised, and auto-simulation). We hypothesized that handwriting dynamics will differ across conditions and that these differences will vary as a function of style.

Method and Materials

The 90 subjects used in this research were all volunteers who were not compensated for their time. The majority (72%) of subjects were women. However, no further gender analysis, such as comparing dynamics between men and women, was performed. Further demographic information regarding the subjects is provided in Table 1.

TABLE 1—*Demographic breakdown of subjects.*

	Male	Female	Age (yrs) 21–30	Age (yrs) 31–40	Age (yrs) 41–50	Age (yrs) 51–60+	Right-handed	Left-handed
Text-based	3	27	20	6	4		29	1
Mixed	11	19	18	7	5		29	1
Stylized	11	19	14	8	4	4	26	4
Total	25	65	52	21	13	4	84	6

Each of 90 writers was asked to provide 20 signatures (10 genuine, five "free-form" disguise, and five "auto-simulations"). Thirty of the writers had a text-based signature, 30 writers had mixed signature styles, and the remaining 30 writers had stylized signatures. There was, therefore, a balanced population distribution among the subjects by signature style.

All signatures were made on copies of a specimen check. For each signature, the check was positioned over a Wacom digitizing pad sampling at 200 Hz and providing 5 μ resolution (Wacom Co. Ltd., Kazo-Shi, Saitama, Japan). The tablet was placed on a horizontal table and writers assumed a comfortable writing position while seated at the table. The writing instrument used was a Wacom inking pen.

For the first 10 signatures, subjects were asked to write their normal signatures (as they would write on a check). These will be referred to as "Genuine" (GEN) signatures. Subjects were then asked to write five signatures in such a way that they could deny having written them at a later date. They were told to disguise their signature in any way they liked and to use different disguise strategies for each of the five if they wished. The scenario for the disguise was signing a check but the receiver would have no idea of the writer's normal signature style. These signatures are referred to as "Disguised" (DIS). The last five signatures were also disguised, however, the writers were told that they were to imagine signing each check in a bank where a specimen signature was available for comparison purposes. The signature must therefore be sufficiently similar to their normal signature such that it would likely pass inspection. These signatures are referred to as "Auto-Simulations" (ASIM). Figure 2 illustrates a mixed-style writer's GEN, DIS, and ASIM signatures.

The collection process resulted in a database of 1800 signatures (900 GEN, 450 DIS, and 450 ASIM).

Dynamic data from each signature were collected using Movalyzer software (V. 4.1) (20). Five parameters were measured. These were duration, size, velocity, jerk (the 3rd derivative of displacement or change in acceleration), and pen pressure. This data obtained from the Movalyzer software were exported to Excel (V. 2003 SP3) and analyzed statistically with Statistica (21). The statistical analysis was conducted in two ways. First, the data were analyzed using a 3×3 analysis of variance (ANOVA) to test for

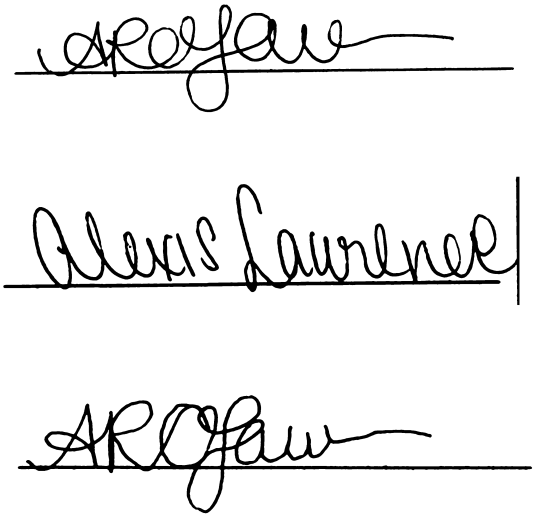

FIG. 2—*Examples of a mixed-style writer's GEN (upper), DIS (middle), and ASIM (lower) signatures.*

TABLE 2—*ANOVA results for condition (GEN, DIS, and ASIM) versus style (text-based, mixed, and stylized) for five parameters (duration, size, velocity, jerk, and pen pressure).*

	Condition	Style	Interaction
Duration	$F_{2,261} = 57.67$ $p < 0.001$	$F_{2,261} = 0.74$ $p > 0.10$	$F_{4,261} = 0.26$ $p > 0.10$
Size	$F_{2,261} = 15.76$ $p < 0.001$	$F_{2,261} = 15.43$ $p < 0.001$	$F_{4,261} = 5.72$ $p < 0.001$
Velocity	$F_{2,261} = 45.19$ $p < 0.001$	$F_{2,261} = 22.14$ $p < 0.001$	$F_{4,261} = 8.56$ $p < 0.001$
Normalized jerk	$F_{2,261} = 12.01$ $p < 0.01$	$F_{2,261} = 2.39$ $p < 0.10$	$F_{4,261} = 0.99$ $p > 0.10$
Pen pressure	$F_{2,261} = 4.18$ $p < 0.05$	$F_{2,261} = 6.46$ $p < 0.01$	$F_{4,261} = 0.40$ $p > 0.10$

main effects and to determine if there were any interactions between signature style and condition. This analysis would determine if the GEN, DIS, and ASIM writing conditions were equally (or differently) influenced by signature styles. Then discriminate function analysis was used to determine if any of the five parameters or a combination of them could predict a GEN, DIS, or ASIM signature with some degree of confidence.

Results

The duration, size, velocity, jerk (a measure of disfluency), and pen pressure of each signature were measured. The means for each of these parameters were calculated and compared across the three signature styles (text-based, mixed, and stylized) and the three conditions (GEN, DIS, and ASIM). A two-way 3×3 ANOVA was used to test any significant differences between the means in the parameters and to look for main effects and interactions.

Table 2 shows a summary of the ANOVA results that are graphically displayed in Figs 3–7.

The ANOVA result for the comparison of signature durations for condition (GEN, DIS, and ASIM) across text-based, mixed, and stylized forms is provided in Fig. 3. No main effects were found for style ($p > 0.10$) but a significant main effect exists for condition ($p < 0.001$). GEN signatures were found to have less duration (were completed more quickly) than both types of DIS signatures. No interaction was found between style and condition ($p > 0.10$). This can be seen in Fig. 3, which shows that the differences in

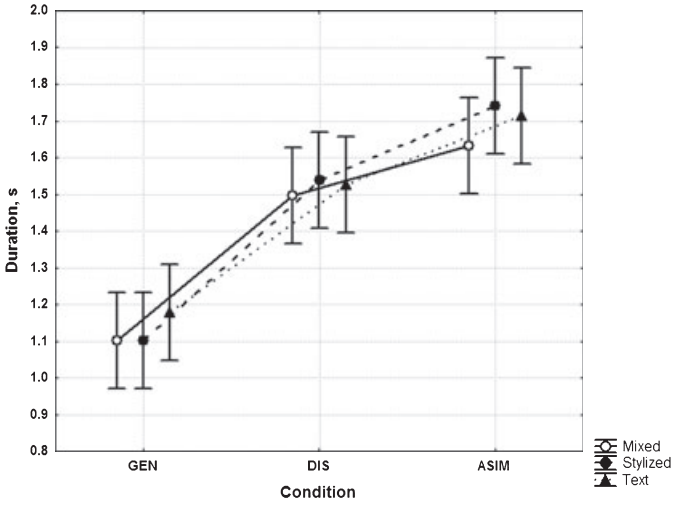

FIG. 3—*Interactions between style and condition for duration.*

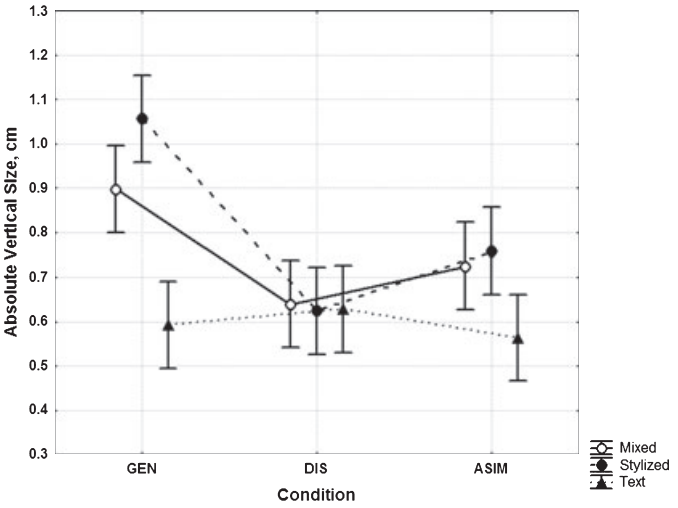

FIG. 4—*Interactions between style and condition for absolute size.*

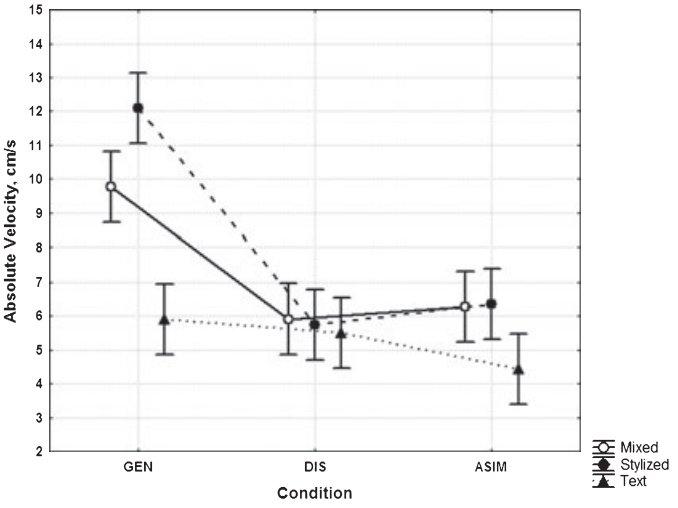

FIG. 5—*Interactions between style and condition for absolute velocity.*

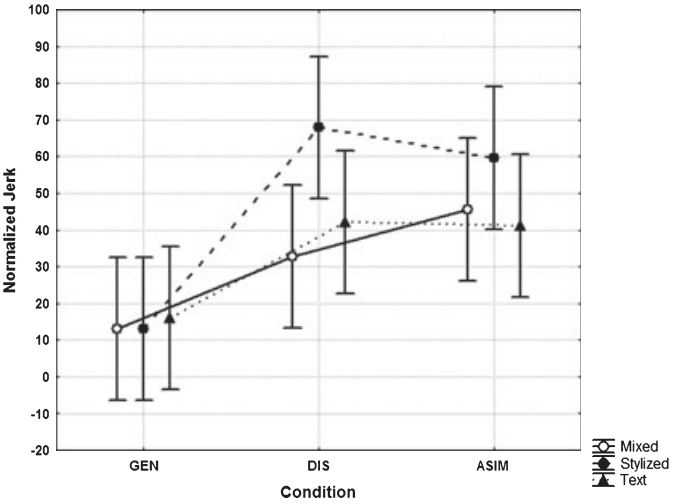

FIG. 6—*Interactions between style and condition for normalized jerk.*

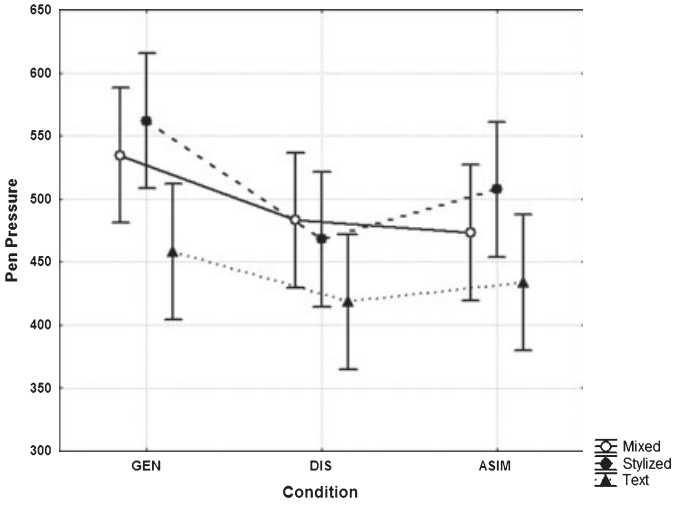

FIG. 7—*Interactions between style and condition for pen pressure.*

duration between the GEN, DIS, and ASIM conditions occurred equally for the three signature styles.

The ANOVA result for the comparison of signature sizes for condition (GEN, DIS, and ASIM) across text-based, mixed, and stylized forms is provided in Fig. 4. A significant main effect was found for style. The text-based signatures were found to be smaller than the mixed and stylized signatures ($p < 0.001$), whereas mixed and stylized signatures did not differ in size. A significant main effect was also found for condition ($p < 0.001$). Both mixed and stylized GEN signatures were larger than DIS and ASIM signatures. There was no significant difference between mixed and stylized GEN signatures. For text-based signatures, there was no difference for size across the conditions.

A significant interaction was found between style and condition ($p < 0.001$) whereby there was a style effect for GEN signatures (text-based signatures being smaller), while none existed for either DIS or ASIM signatures.

The ANOVA result for the comparison of signature velocities for condition (GEN, DIS, and ASIM) across text-based, mixed, and stylized forms is illustrated in Fig. 5. Significant main effects were found for style ($p < 0.001$) and condition ($p < 0.001$) with a significant interaction ($p < 0.001$). Text-based GEN signatures were written slower than mixed or stylized GEN signatures with no significant differences found between mixed and stylized signatures. There was no difference between styles for DIS and ASIM signatures. GEN mixed and stylized signatures were written faster than both DIS and ASIM signatures, which did not differ. There was no difference in velocity for text-based signatures over the three conditions.

The ANOVA result for the comparison of signature jerk (disfluency) for condition (GEN, DIS, and ASIM) across text-based, mixed, and stylized forms is provided in Fig. 6. A significant main effect was found for condition ($p < 0.01$). GEN signatures displayed less jerk (written more fluently) than DIS and ASIM signatures, which did not differ. There were no differences between styles ($p < 0.10$) and no significant interaction between style and condition for the measure of disfluency ($p > 0.10$).

The ANOVA result for the comparison of signature pen pressure for condition (GEN, DIS, and ASIM) across text-based, mixed, and stylized forms is provided in Fig. 7. A significant main effect was found across styles ($p < 0.01$). Text-based signatures were written with less pen pressure than mixed or stylized signatures while the latter two styles were similar. A significant main effect was found for condition ($p < 0.05$). GEN signatures were written with greater pen pressure than DIS but not ASIM signatures. No significant interaction was found between style and condition for the measure of pen pressure ($p > 0.10$).

TABLE 3—*Results of discriminate function analysis based on five parameters showing percentage accuracy in discriminating between conditions and styles.*

Condition	Text-based	Mixed	Stylized
GEN v DIS			
GEN	90.0	83.3	76.6
DIS	76.6	83.3	90.0
ALL	83.3	83.3	83.3
DIS v ASIM			
DIS	63.3	73.3	70.0
ASIM	70.0	60.0	63.3
ALL	66.6	66.6	66.6
GEN v ASIM			
GEN	90.0	90.0	93.3
ASIM	80.0	73.3	80.0
ALL	85.0	81.6	86.6

Discriminate Function Analysis

Discriminate function analysis was used to determine whether groups of writers could be distinguished based on a set of variables. The five parameters (duration, size, velocity, jerk, and pen pressure) were assessed to determine if they could discriminate between the conditions for each signature style.

Using these five parameters, GEN and ASIM signatures were discriminated with accuracy greater than 80%. Text-based signatures were discriminated with an overall accuracy of 85%; mixed signatures were separated with an accuracy of 81.6%, while stylized signatures were distinguished with an accuracy of 86.6%. An overall 83.3% accuracy rate was achieved for discriminating between GEN and DIS signatures across all signature styles.

This model was able to discriminate 66.6% of DIS and ASIM signatures over all signature styles (Table 3). A stepwise procedure was applied to improve the discrimination. A 2-factor model consisting of size and velocity resulted in an improvement from 66.6% to 71.6% for text-based signatures. The stepwise procedure showed no improvement in accuracy for all other style/condition combinations.

Discussion

To our knowledge, this is the first study to compare the dynamics of different styles of signatures. A major feature of the results is the difference in dynamics for stylized compared to text-based GEN signatures. Stylized GEN signatures were larger, written with higher velocity, and pressure than text-based signatures.

Research by FDEs has shown that writers disguise their signatures by changing the slant, shape, size, speed, and fluency of letters. However, previously reported research does not discriminate between different styles of signatures. This study investigated whether there is any relationship between signature styles and the conditions of GEN, DIS, and ASIM. We hypothesized that handwriting dynamics would differ across conditions and that these differences would vary as a function of style. There was some support for this but not for all parameters and all conditions.

Text-based signatures showed changes in fewer parameters across conditions than stylized or mixed signatures. For text-based

signatures, duration was an important discriminator between GEN and both DIS and ASIM signatures although the DIS and ASIM signatures could not be separated by the duration parameter. Therefore, if FDEs could reliably determine the duration of a text-based signature from a static trace, the rate of accuracy of determinations whether such signatures are GEN or DIS/ASIM would be increased.

For mixed-style signatures, velocity and size were found to be significant in separating GEN from both DIS and ASIM signatures. GEN and ASIM signatures could be distinguished by considering their duration.

For stylized signatures, three parameters—velocity, size, and jerk (disfluency) were significant in separating GEN from both DIS conditions, while duration was important in separating GEN from ASIM signatures. This indicates that FDEs have a better chance of discriminating between GEN and both DIS conditions if signatures are stylized rather than text-based or mixed.

The discriminate function analysis showed that DIS and ASIM signatures were classified with relatively low accuracy (66.6%) based on the five selected parameters. One possible reason for this is that some writers may have used similar strategies for DIS and ASIM signatures. The dynamic differences between the DIS and ASIM signatures would not be significant in such a case. Examples of such strategies are shown in Fig. 8.

Analysis of the data showed that some signatures can be classified with a relatively high degree of accuracy. The task ahead for FDEs is to increase the level of accuracy in differentiating between GEN and DIS or ASIM signatures.

It was noted that GEN signatures were written with more pen pressure than DIS and ASIM signatures. It might be expected that a writer would apply more pressure when disguising his or her signature because more thought is required in executing the disguise. Van Gemmert et al. (14) found that "increase of pen pressure is higher in the cursive than in the printing style samples of DIS script. This may seem as a confirmation of the view that using a DIS print letter style is less demanding than using a cursive style." Writers who utilize printed letter forms as a disguise are apt to exert less pen pressure in their DIS signatures.

It was interesting that no significant difference was noted in pen pressure for the GEN and auto-simulation signatures. This is in agreement with previous studies which found that "generally speaking, the overall pressure patterns of a writer's signature have been shown to be habitual and highly individualistic to that writer" (22) and that "Dynamic pressure patterns are an integral part of an individual's signature" (23). If pen pressure is an ingrained motor-control characteristic, then even though a writer is auto-simulating his/her signature, this writing habit may be too powerful to change. Further research is needed to confirm this finding.

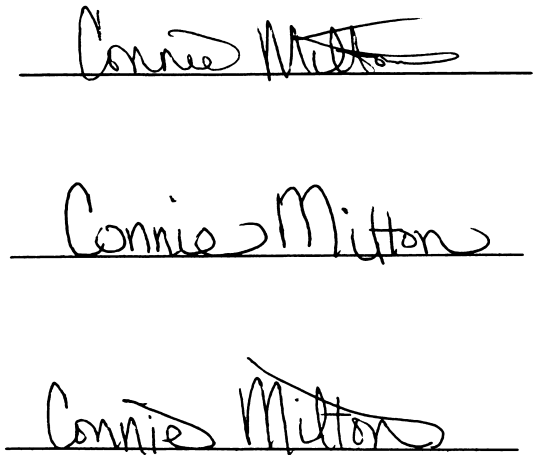

FIG. 8—*An example where a writer employed similar strategies for DIS (middle) and ASIM (lower) signatures. The writer's GEN signature is uppermost.*

This study confirms the results of previous research that claim size, speed, and fluency are important factors in differentiating GEN signatures from DIS signatures. The results also showed that FDEs have to take the style of a signature into consideration when evaluating it as being GEN, DIS, or an ASIM. However, FDEs need to develop a means of quantitatively measuring these parameters from static signatures.

Conflict of interest: The authors have no relevant conflicts of interest to declare.

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Additional information and reprint requests:
Linton A. Mohammed, M.F.S.
Forensic Document Examiner
923 Merlo Court
Carlsbad, CA 92011
E-mail: lamqde@gmail.com