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Using Acceleration/Deceleration Plots in the Forensic Analysis of Electronically Captured Signatures

Kathleen Annunziata Nicolaides

Affiliated Forensic Laboratory, Inc., 3030 North Central Avenue, Suite 1206, Phoenix, Arizona 85012

A research study was conducted to determine if analysis and comparison of acceleration/deceleration plots of signature data captured by electronic signature tablets would provide meaningful evidence in an examination of electronically captured signatures. This research focused on data collected by signature tablets produced by Topaz Systems, Inc., one of the largest suppliers of digital capture devices. William Flynn, in his article "Conducting a Forensic Examination of Electronically Captured Signatures" (published in the June 2012 edition of the ASQDE Journal), noted the visual differences in the plots of genuine and simulated signatures. Further research was conducted to determine how useful plotting the acceleration/deceleration of electronic signatures would be in a forensic examination and what reliable conclusions could be made from their analysis. The study hypotheses were that acceleration plots will be consistent for one writer; that simulated, traced, and spurious signature plots will be visually different from those of genuine signatures; that there will be a noticeable difference between signature plots of different writers; and that the comparison of acceleration plots will be a useful tool for signature authentication.

Introduction

At ASQDE's 2011 meeting, William J. Flynn, Chief Forensic Document Examiner at Affiliated Forensic Laboratory, presented research and methodology for the examination of electronically captured signatures. Over a decade ago, Mr. Flynn worked with Topaz Systems, Inc., a leading provider of signature capture devices, in developing analytical tools for the forensic examination of electronic signatures. These software tools, SigAnalyzeä and SigCompareä, are available to forensic document examiners and provide a "full resolution" plot of a signature, information on the number of digital "strokes" comprising each signature, and the time taken to execute each stroke. Mr. Flynn, however, found that by importing the electronic signature's raw data into an Excel spreadsheet, additional details about the signature's formation, sequence of strokes, and dynamics could be plotted and used in the forensic examination.

In the June 2012 edition of the Journal of the American Society of Questioned Document Examiners, Mr. Flynn's paper "Conducting a Forensic Examination of Electronically Captured Signatures" details how signature data is captured by a Topaz pad, what data is contained in a raw signature file, how this data can be imported into an Excel spreadsheet, how an accurate representation of the signature can be plotted, and how a signature's speed dynamics can be visualized with an acceleration/deceleration graph.

In Mr. Flynn's paper, he observed a visual difference in the acceleration/deceleration plots of genuine and simulated signatures. This study was undertaken to test Mr. Flynn's observations. Research was conducted to determine how useful plotting the acceleration/deceleration of electronic signatures would be in a forensic examination and what reliable conclusions could be made from their analysis. The study hypotheses were that acceleration/deceleration plots would be consistent for one writer; that simulated, traced, and spurious[1] signature plots would be visually different from those of genuine signatures; that

[1]The term "spurious" refers to non-genuine signatures where no attempt has been made to simulate or imitate.

there would be a noticeable difference between signature plots of different writers; and that the comparison of acceleration plots would be a useful tool for signature authentication.

Methods and Materials

Signatures were collected at SWAFDE meetings and at Affiliated Forensic Laboratory in 2011 and 2012 using a Topaz Model T-S751-HSB Signature Capture Tablet, a stylus with a ballpoint pen insert, and Topaz SigPlusâ software. Subjects were asked to provide samples by signing on paper positioned on top of the signature pad. In this way, both a "wet signature" and an electronic signature were collected simultaneously. In most cases, subjects were asked to provide 3 samples of requested signature types. Subjects were seated and were allowed to position the capture tablet so that they could write naturally. Subjects were allowed to practice simulating model signatures before providing electronic simulations. Some subjects who provided traced signature samples at the 2012 SWAFDE meeting commented that they had difficulty seeing the underlying model signature; other subjects commented that they found it challenging to provide spurious signatures since they did not write cursive often.

119 signatures from 25 different writers were used in this study. There were 71 genuine signatures, 12 simulated signatures, 12 traced signatures, 12 spurious signatures, and 12 auto forgeries. For each electronic signature, the raw data was imported into an Excel spreadsheet and both a signature plot and an acceleration/deceleration plot were created. The signature plot could be compared to the "wet signature" to verify that the data was correctly labeled.

Once all the acceleration/deceleration plots associated with one person's signature were created, the horizontal and vertical axes were set to the same values so that the plots could be easily compared. When evaluating plots, there were 3 characteristics that were compared: 1) the range of variation in the units graphed in the vertical axis (distance); 2) the total number of data pairs graphed in the horizontal axis (time taken to execute signature); and 3) the overall visual representation of the data (the graph's pattern).

It should be noted that although characteristics such as acceleration and duration are being plotted in this study, and while the plots are pictorially similar to those seen on page 98 of Caligiuri and Mohammed's book, The Neuroscience of Handwriting, the plots are not comparable. Dr. Mohammed's excellent kinematic studies use different digitizing tablets, different software, and deconstruct signatures in a different way. This study centers on the practical use of acceleration/deceleration plots in a forensic electronic signature examination and whether their evaluation would be valuable.

Analysis

Hypothesis #1: acceleration/deceleration plots will be consistent for one writer

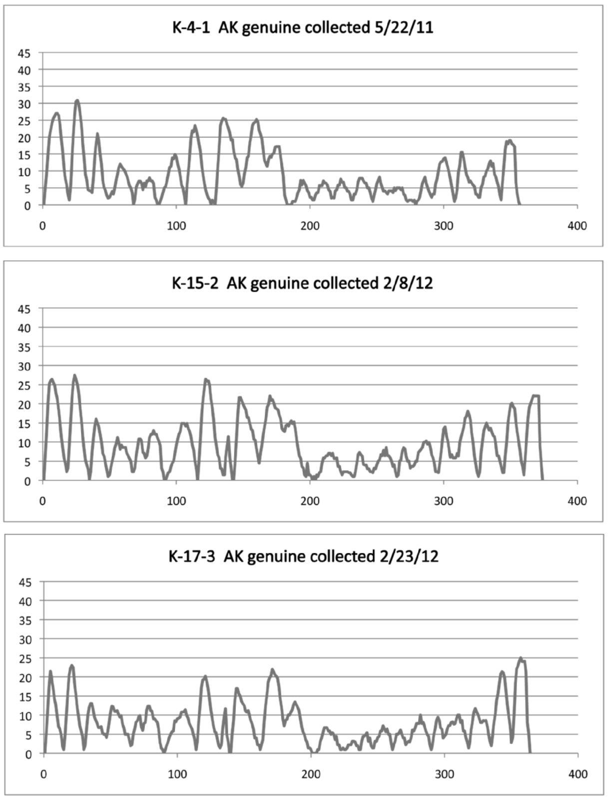


Figure 1. Plots of genuine AK signatures collected on different days.

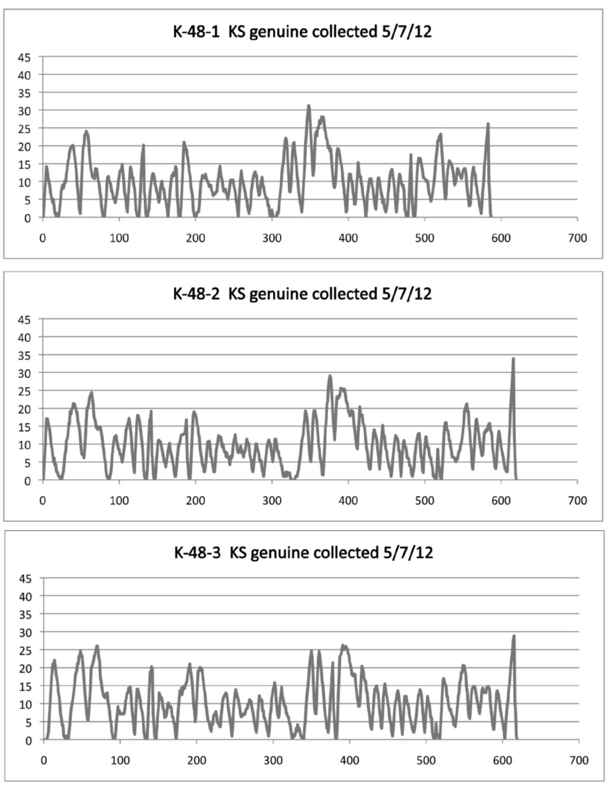


Figure 2. Plots of genuine KS signatures executed consecutively.

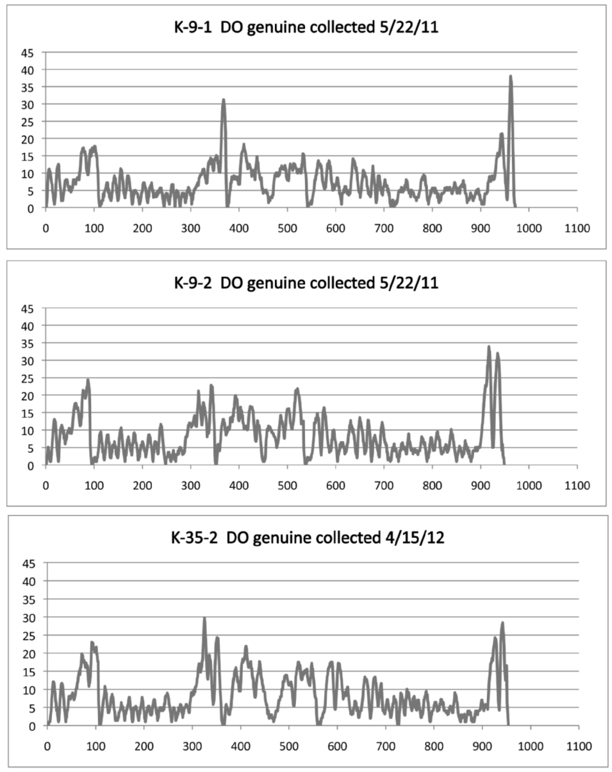


Figure 3. Plots of genuine DO signatures collected on different days.

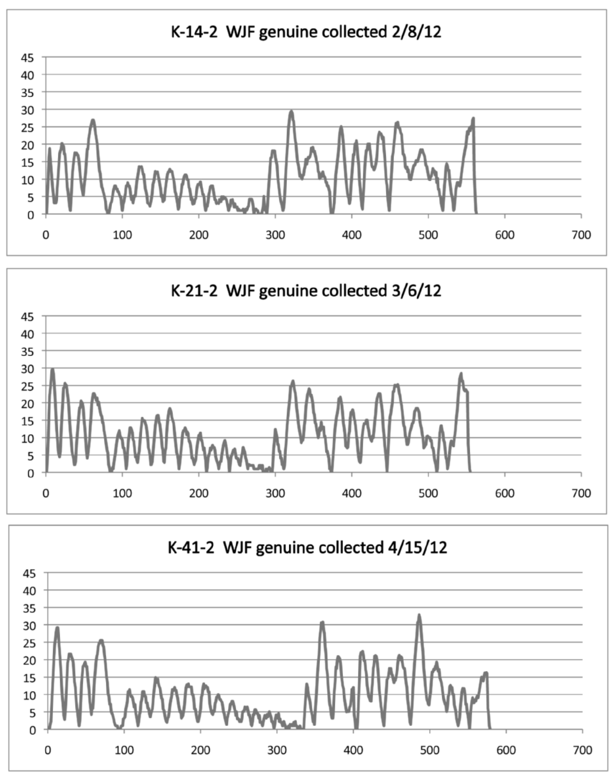


Figure 4. Plots of genuine WJF signatures collected on different days.

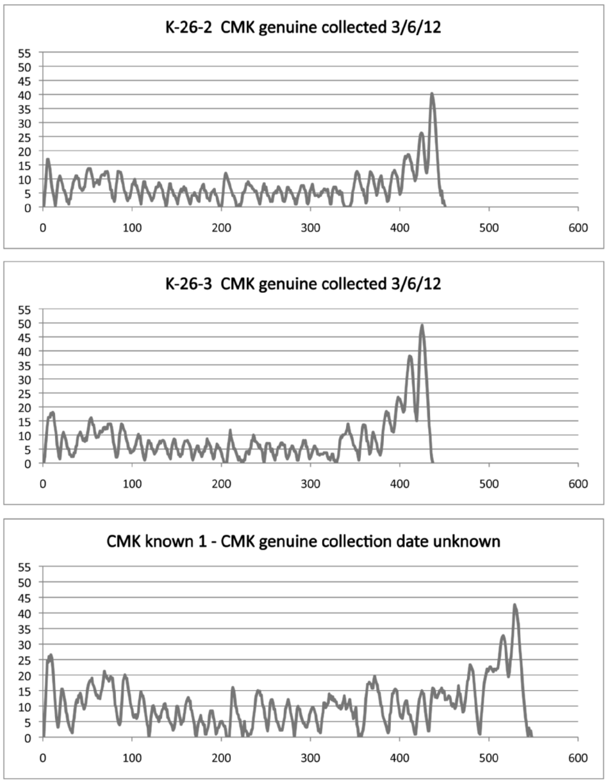


Figure 5. Plots of genuine CMK signatures collected on different days.

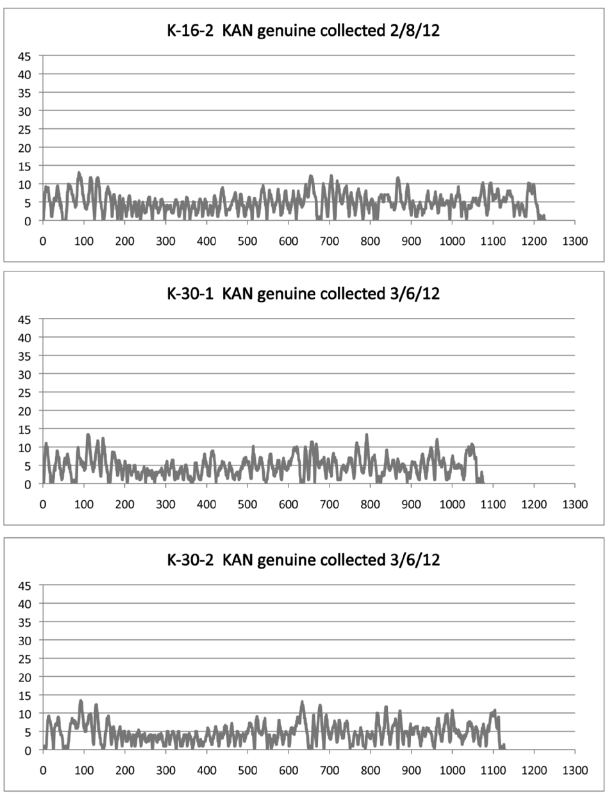


Figure 6. Plots of genuine KAN signatures collected on different days.

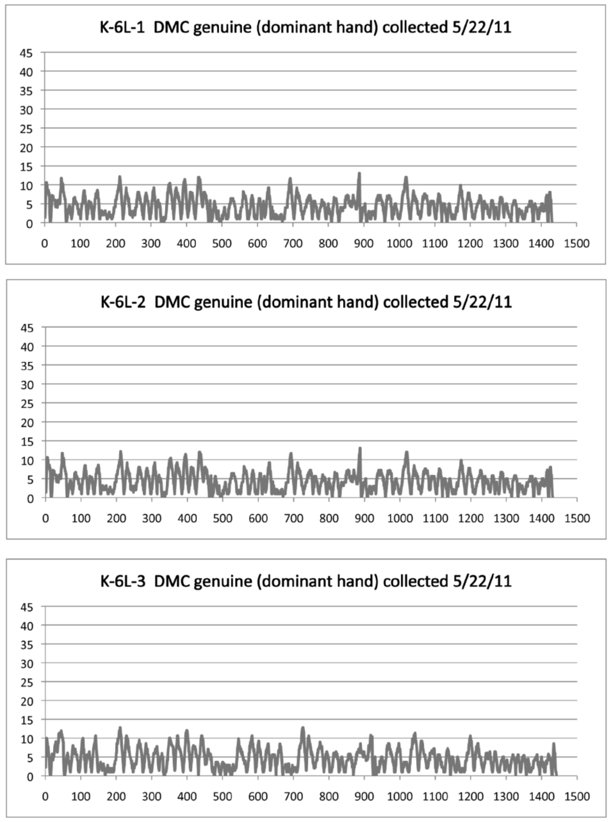


Figure 7. Plots of genuine DMC signatures executed consecutively.

The acceleration/deceleration plots of 71 genuine signatures from 20 different writers were analyzed. As demonstrated in the above samples (see Figures 1–7), a consistent pattern was observed in the plots of a single writer, even among signatures collected on different days.

It was noted that plot patterns mapping a wide variation in acceleration/deceleration movements were much easier to discern than plots mapping a long series of movements that did not exceed 15 units. In the samples above, this is well demonstrated in the WJF plots where movements accelerate to 30 – 35 units (see Figure 4) as opposed to the KAN plots where movements range between 5 and 13 units (see Figure 6).

Just as some writers have a wider range of variation from one signature to the next, the acceleration/deceleration plots reflected the variations observable in the wet signatures such as size or length of strokes. For example, HR's wet signatures show a greater range of variation than J T's signatures (see Figure 8). Their respective acceleration/decleration plots show a corresponding variation.

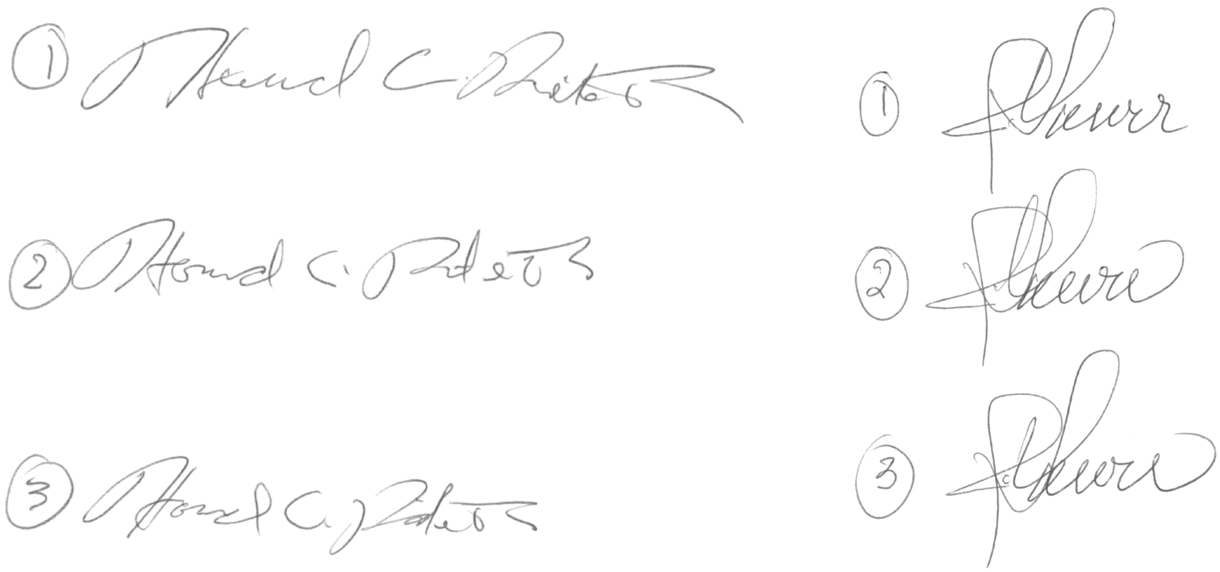


Figure 8. Scans of the original, "wet" signatures of HR and JT plotted in Figures 9 and 10.

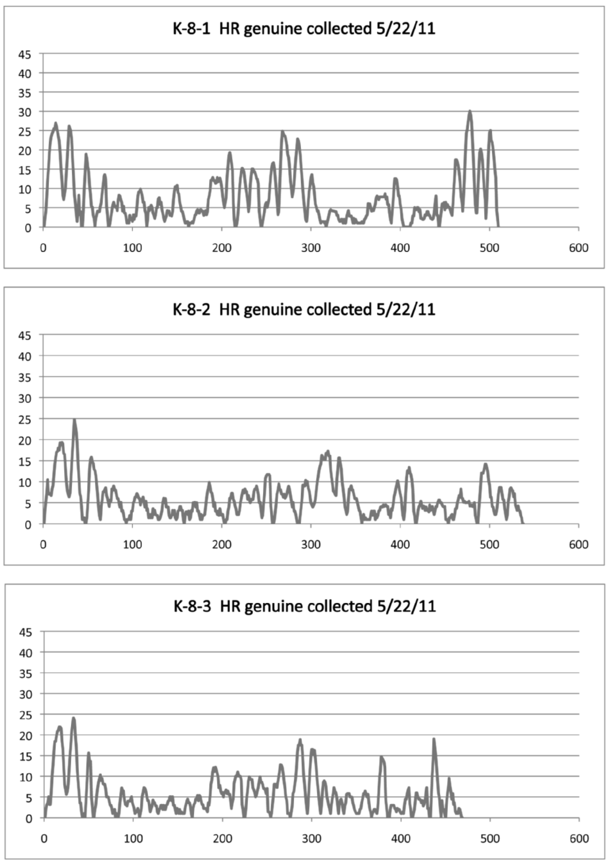


Figure 9. Plots of genuine HR signatures executed consecutively.

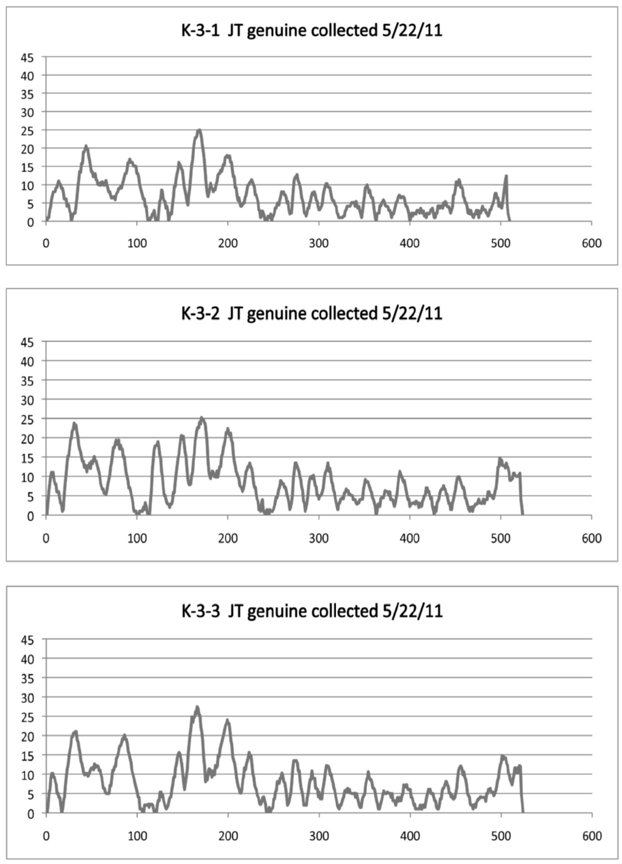


Figure 10. Plots of genuine JT signatures executed consecutively.

HR executed his 3 signatures using 8, 7, and 11 strokes respectively, in an average of 3.8 seconds, with a .52 difference in seconds between his fastest and slowest speed. JT executed all 3 of his signatures using 4 strokes, in an average of 3.9 seconds, with only a .11 seconds difference between the fastest and slowest execution.

If we look at HR's signatures, while there is variation in the sizes of the signatures, there is similarity in the proportions and formations of the "H" and "Jr" – large movements that would cause higher peaks in the acceleration/deceleration plots. The similar plot pattern of HR's signatures is more apparent when the acceleration/deceleration plots are aligned by first and final movements rather than time.

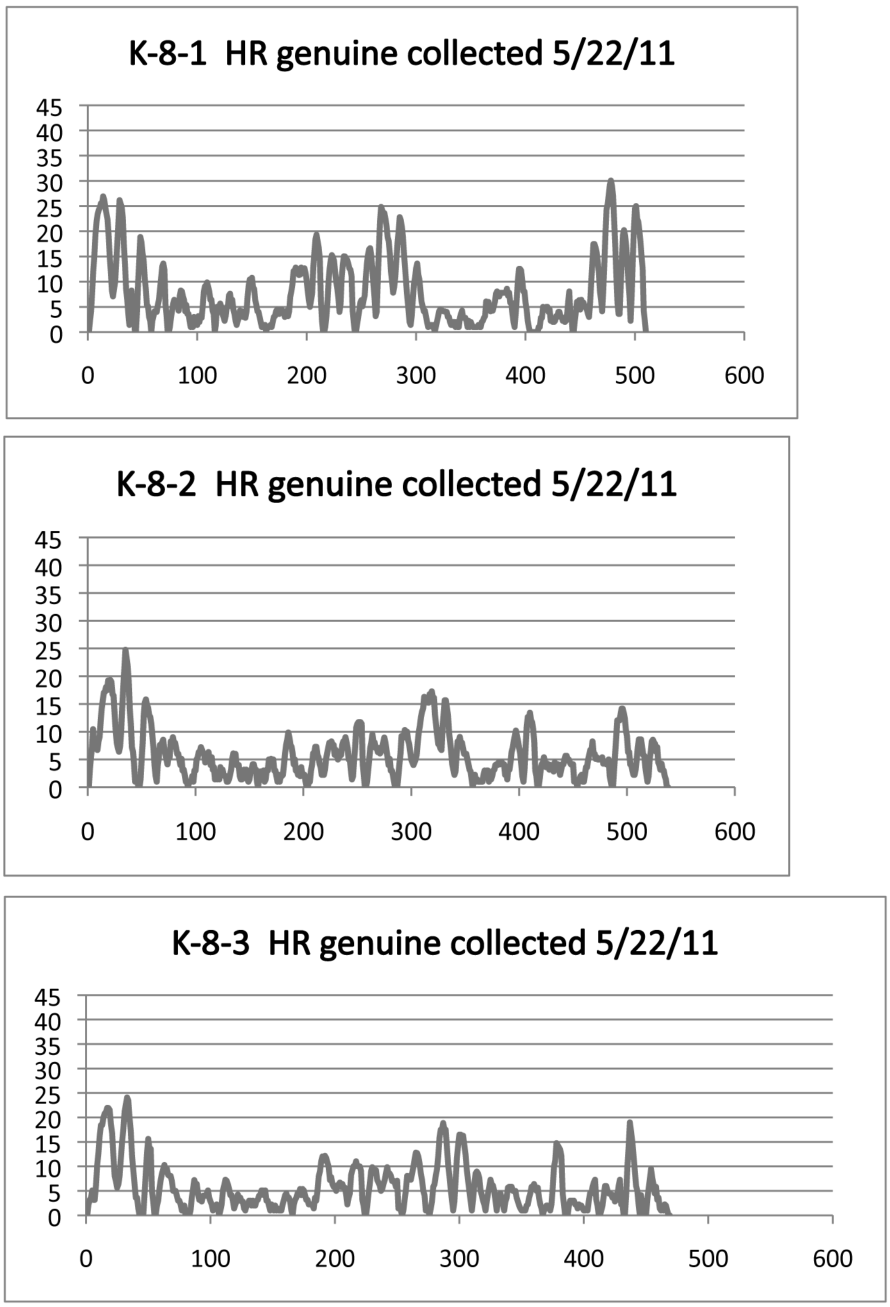


Figure 11. Similarities in HR's plot patterns are more evident when the plots are aligned by the large first and final movements, rather than by time.

It is clear that acceleration/deceleration plots are much more consistent in writers who sign their name in a consistent fashion. This makes sense since the plots are showing how the hand is speeding up and slowing down when forming letters. If the letters themselves are formed differently, then the same acceleration/deceleration plot pattern could not be expected. Likewise, if the sizes or number of letters or movements vary, then the acceleration/deceleration plots would reflect this with taller, shorter, or fewer peaks.

Hypothesis #2: acceleration/deceleration plots of various writers will be visually different

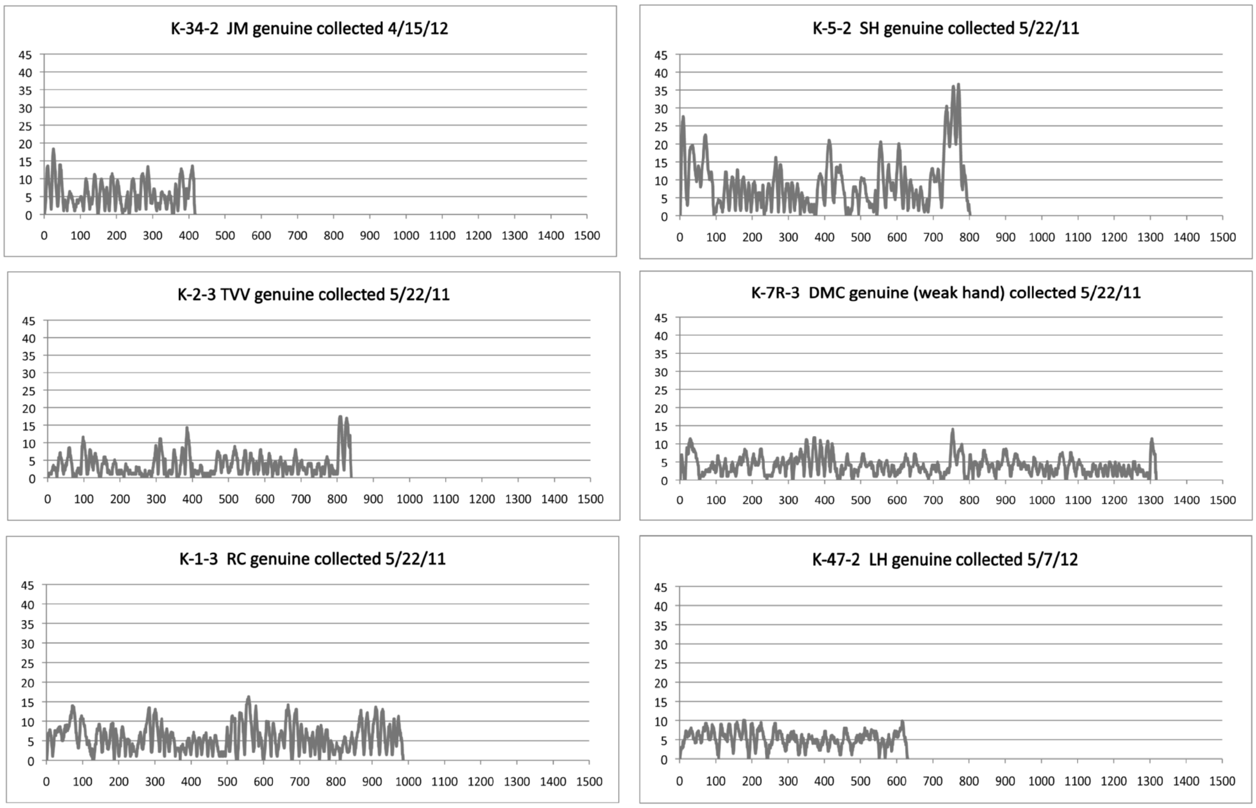


Figure 12. Plots of genuine signatures of different writers.

Acceleration/deceleration plots graph the distance between each of the data pairs comprising an electronic signature. The vertical axis represents the distance while the horizontal axis represents the sequential number of the data pair, and, since data pairs are collected at a certain rate, the horizontal axis ultimately represents the time taken to execute the signature. For instance, in the above K-5-2 plot (see Figure 12), a little over 800 data pairs were collected while SH executed this signature. The Topaz tablet used to collect this signature captures 133 data pairs per second. So, by dividing the total number of data pairs (802) by 133, we know that SH executed this signature in 6.03 seconds.

Therefore, in order to accurately compare plot to plot, both the vertical and horizontal axes were set to the same maximum units. One will note that the plots in the previous section are set to the same maximum units *for the same writer*. To now compare plots of *different writers*, the vertical and horizontal axes were reset, if needed, for comparison from one writer to the next.

As was observed in the plots from a single writer, the plots from writers who had a wide range of acceleration/deceleration movements could be easily differentiated (See Figure 12). However, a much closer study was required for differentiation of writers who took similar amounts of time to execute their signature and who did not have a wide variation in their acceleration/deceleration movements. This is illustrated in the plots of DMC and KAN's signatures in Figure 13.

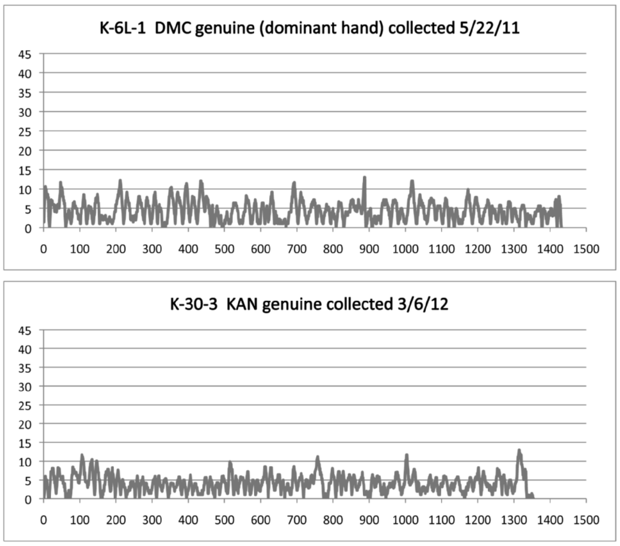


Figure 13. Plots of genuine signatures of DMC and KAN. Both signatures have a narrow range of variation in distance, with acceleration peaks below 15 units.

One recommended method for analyzing two acceleration/deceleration plots with a narrow variation in distance would be to reset the axes for the most detailed viewing. For instance, the maximum distances reached in the K-6L-1 and K-30-3 plots are less than 15. By resetting the vertical axis to a maximum of 15 units, additional details can be seen for comparison (see Figure 14).

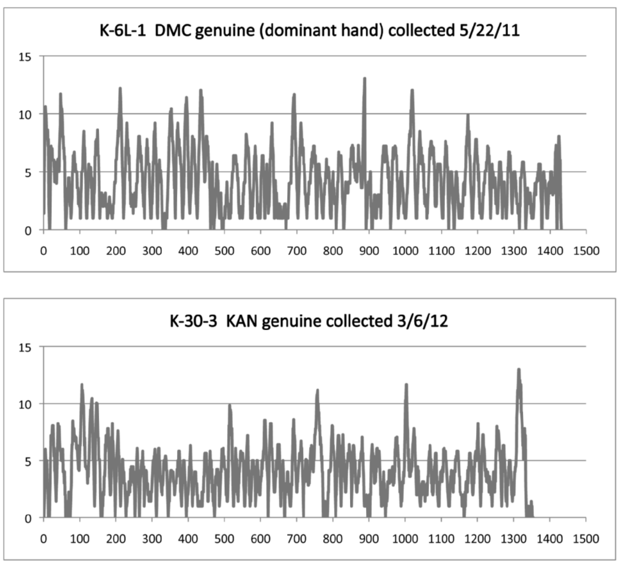
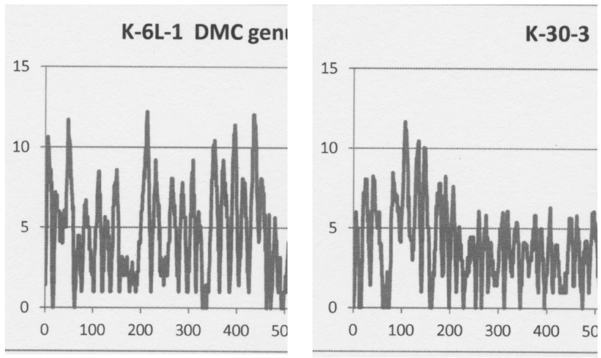


Figure 14. The same signatures of DMC and KAN seen in Figure 13, plotted on a graph with a maximum vertical axis of 15.

With the expanded view, the differences in the acceleration/decelerations below and above the 5 units are more easily observed. Dividing the plots into segments also helps with comparison, as illustrated below.



Hypothesis #3: acceleration/deceleration plots of simulated, traced and spurious signatures will be visually different than those of genuine signatures

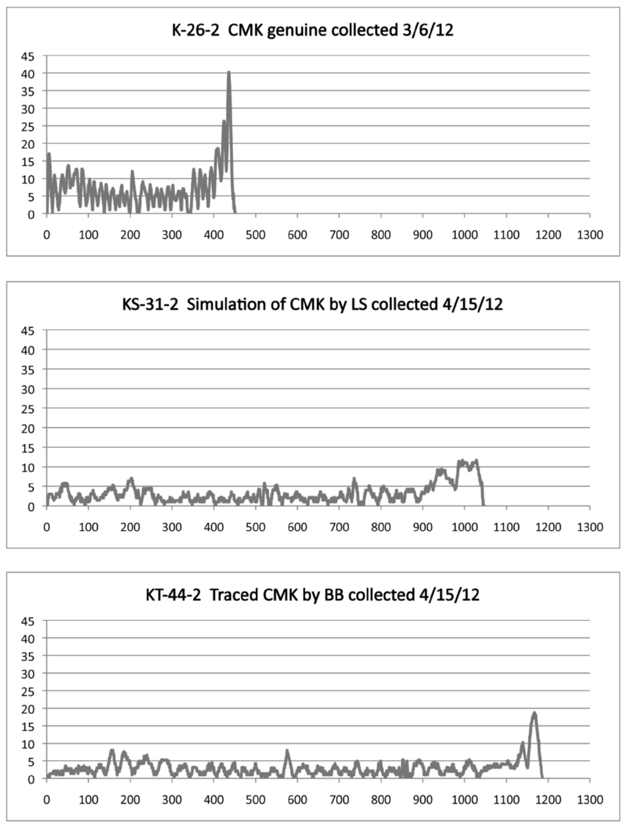


Figure 15. Plot of a genuine CMK signature above a simulated and a traced CMK signature by different writers.

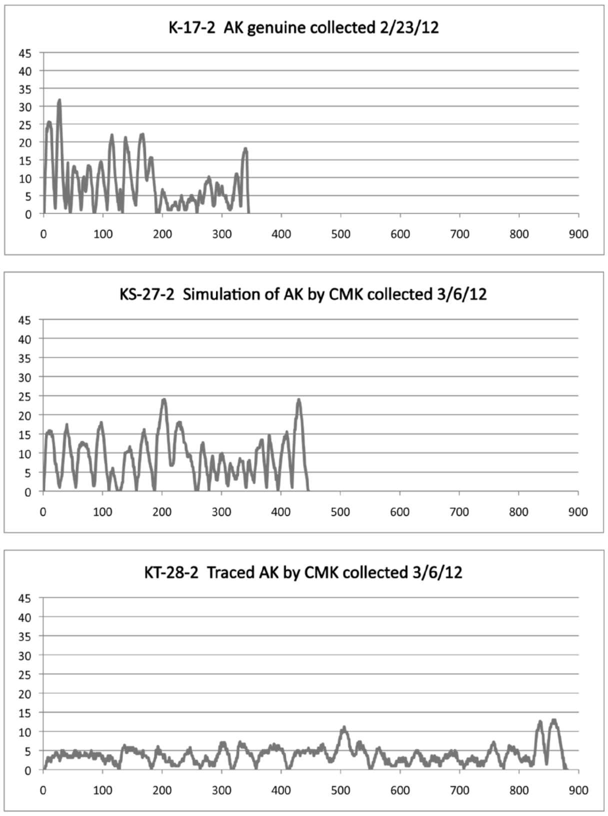


Figure 16. Plot of a genuine AK signature above a simulated and a traced AK signature by one writer.

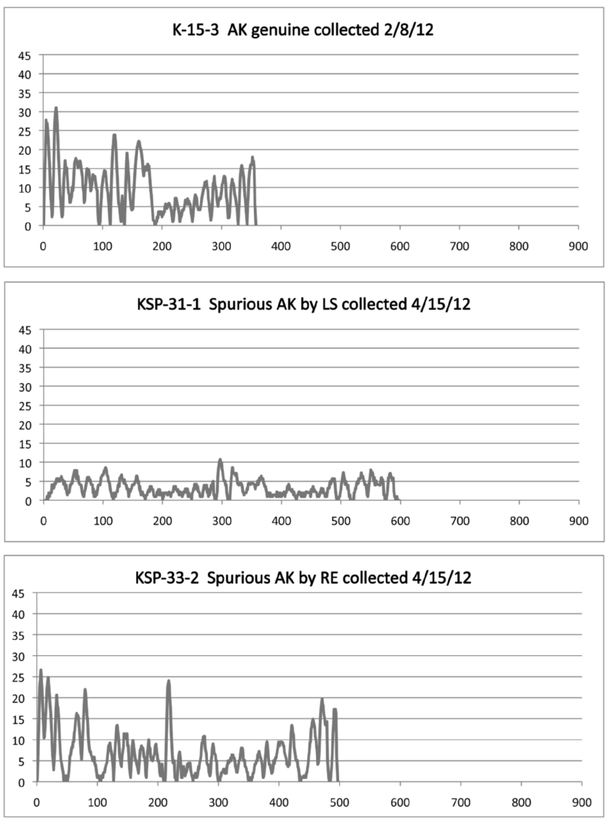


Figure 17. Plot of a genuine AK signature above spurious AK signatures by different writers.

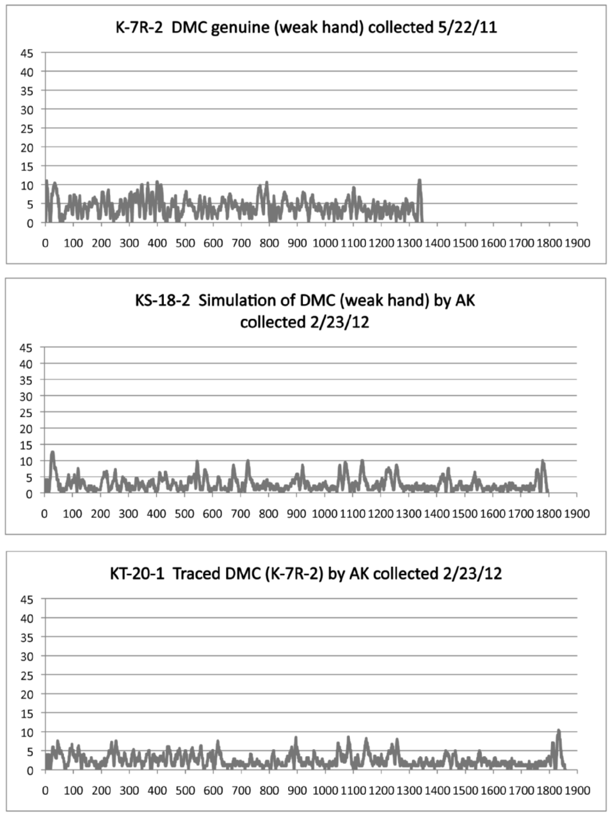


Figure 18. Plot of a genuine DMC weak hand signature (DMC is ambidextrous) above a simulated and a traced DMC signature by one writer.

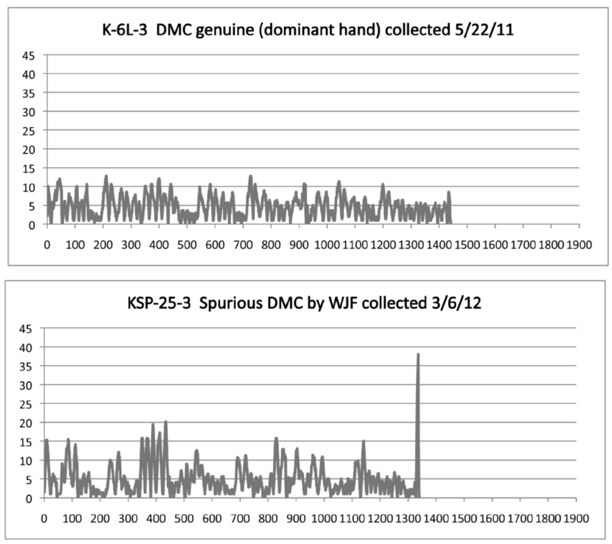


Figure 19. Plot of a genuine DMC dominant hand signature (DMC is ambidextrous) above a spurious DMC signature.

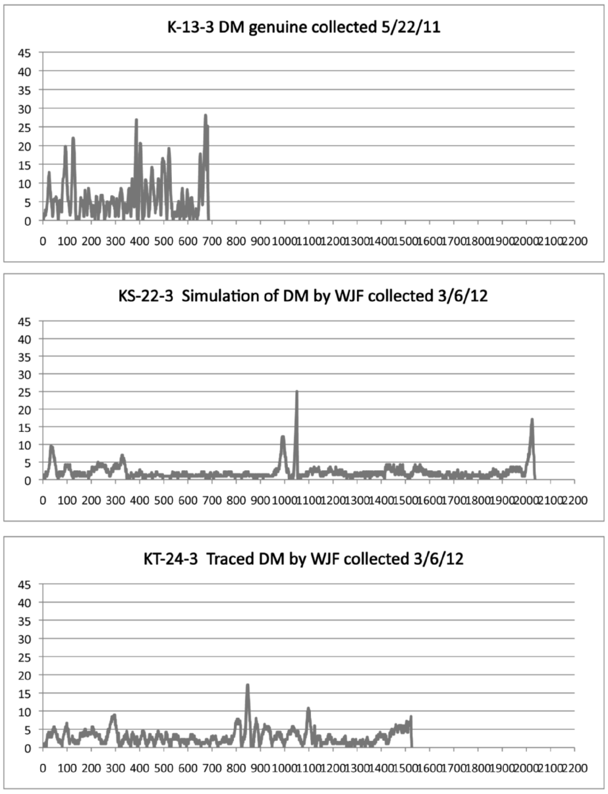


Figure 20. Plot of a genuine DM signature above a simulated and a traced DM signature by one writer.

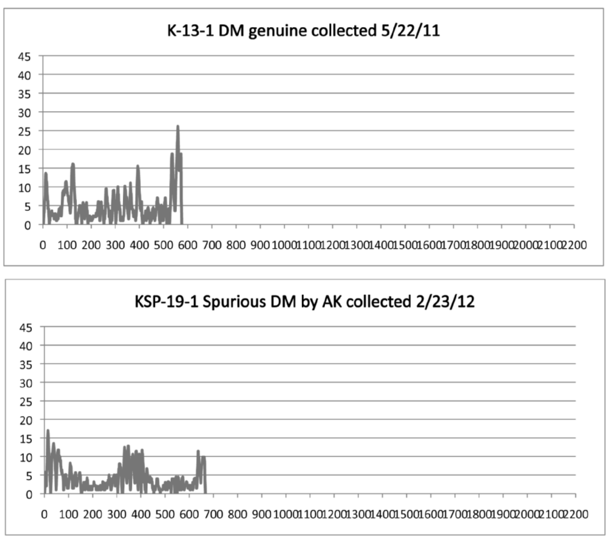


Figure 21. Plot of a genuine DM signature above a spurious DM signature.

As was expected, most plots of the simulated and traced signatures were dramatically different than the genuine plots, both in the variation of acceleration/deceleration movements and the speed of execution. As would also be expected, since spurious signatures (see Figures 15, 16, 18, and 20) are written in the author's own handwriting, the speed of spurious signatures varied between different writers, but could be close to the genuine writer's. Nonetheless, even if the spurious signature (see Figures 17, 19, and 21) was executed at the same approximate speed, the acceleration/deceleration movements were different and resulted in a visually different plot. See Figures 22 and 23 for illustration.

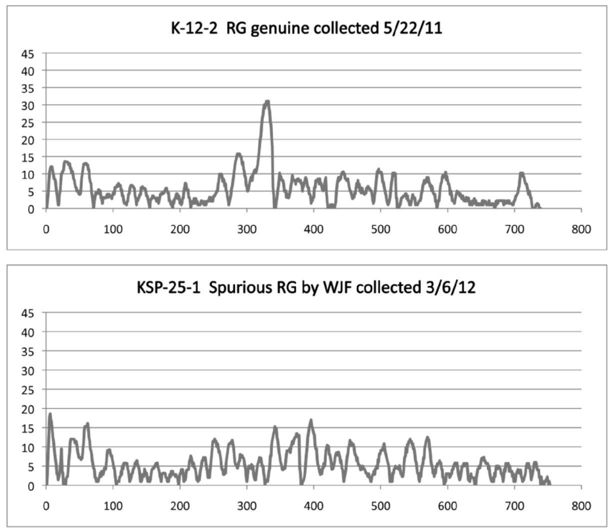


Figure 22. Plot of a genuine RG signature above a spurious RG signature.

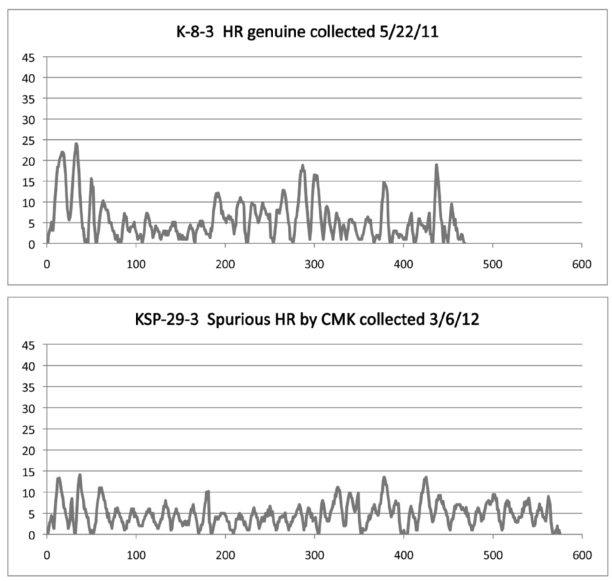


Figure 23. Plot of a genuine HR signature above a spurious HR signature.

Examples of auto forgery were also collected from 4 different writers. As in other non-genuine or unnatural signatures, these plots were differentiable from those of natural, genuine signatures (see Figures 23 – 26).

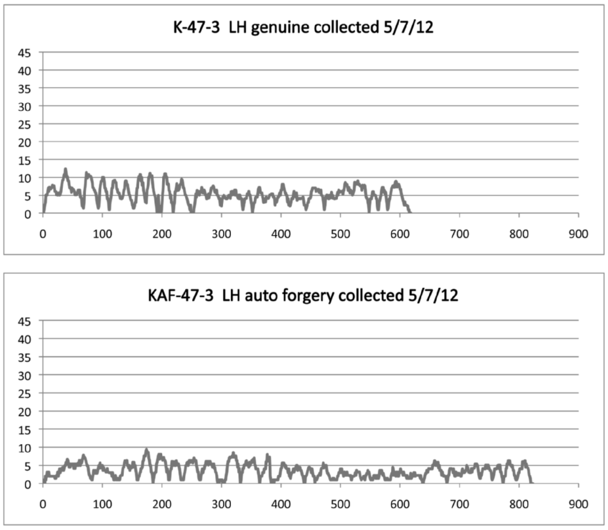


Figure 23. Plot of a genuine LH signature above a LH auto forgery.

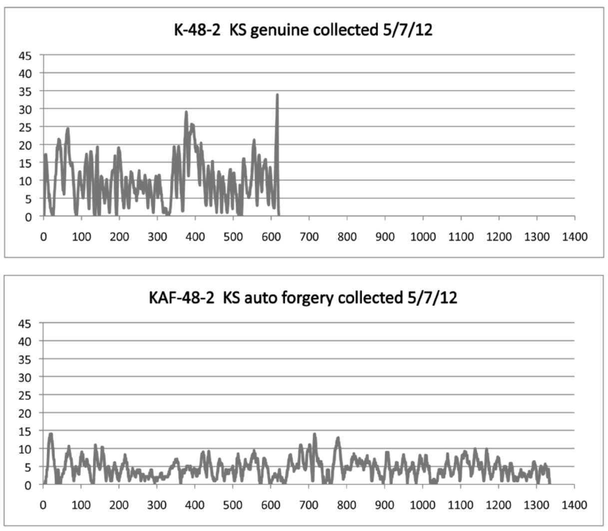


Figure 24. Plot of a genuine KS signature above a KS auto forgery.

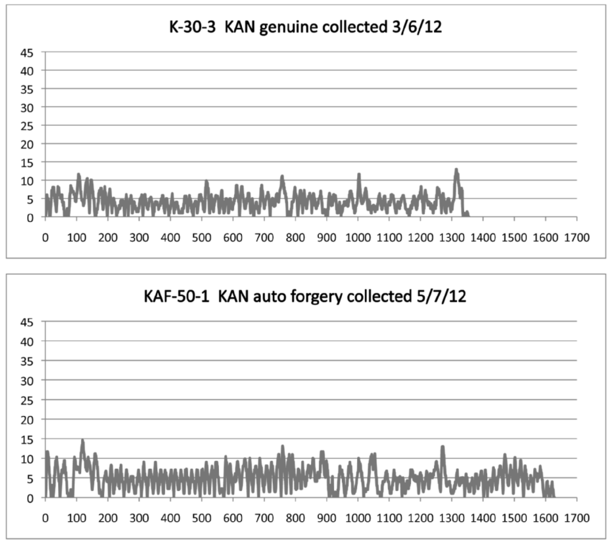


Figure 25. Plot of a genuine KAN signature above a KAN auto forgery.

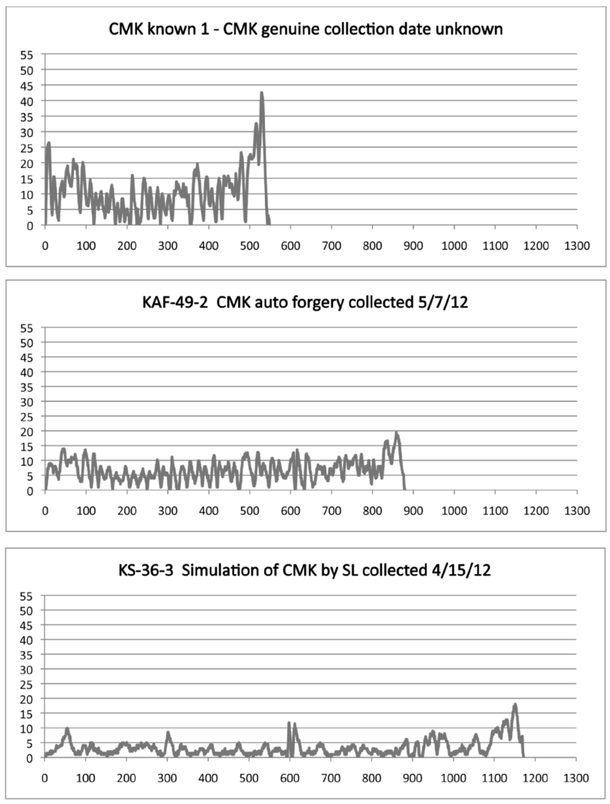


Figure 26. Plot of a genuine CMK signature above a CMK auto forgery and a simulated CMK signature.

Some similarities in the acceleration/deceleration patterns of the genuine and auto forgeries were observed. Further research is needed in this area. Only one of the contributors had samples of simulated signatures which could be compared to the auto forgeries. Additional samples are needed before reliable conclusions can be made regarding the general characteristics of auto forgery plots.

Hypothesis #4: the comparison of acceleration/deceleration plots will be a useful tool for electronic signature authentication

Since the previous 3 hypotheses of this study proved to be true, then this hypothesis is also true. Had the acceleration/deceleration plots of the same writer not been similar, and had plots of different writers been the same, and plots of simulations, tracings and spurious signatures been indistinguishable from the genuine signature plots, then the examination of these plots would provide no meaningful evidence. However, because this study has shown that there is a consistent pattern to acceleration/deceleration plots of one writer; that plots of different writers can be distinguished from each other; and that plots of simulated, traced, or spurious signatures are significantly different than those of the genuine signatures, the comparison of acceleration/deceleration plots of questioned and known electronic signatures would provide useful information.

At this point in our research, it is recommended that analysis of acceleration/deceleration plots be only one part of a comprehensive electronic signature examination. I would advise against basing a conclusion solely on the analysis of acceleration/deceleration plots. Rather, the acceleration/deceleration plots should be analyzed in conjunction with the dynamic data and the plotted signature graphs.

Discussion

The raw data for each Topaz .sig file includes the total number of data pairs, the number of digital strokes used to create the signature, and the sequential number of the last data pair of each stroke. By subtracting the sequential number of the previous stroke from the sequential number of the current stroke, the number of data pairs in each stroke can be calculated. For example, to calculate the number of data pairs in stroke 2 of the "CMK known 2" signature in Figure 27, the following formula was used: 207 – 187.

During the course of this study, data on the number of strokes, total number of data pairs, and number of data pairs in each stroke were compiled for analysis. An example of the information collected for each signature is provided below:

Sig #	Name	Total # Data Pairs	# Strokes	Sequential # of Last Data Pair of Stroke	# Data Pairs in Stroke		Time = Total # Data Pairs / 1/133 sec.
CMK known 2	CMK	486	4	187	187	stroke 1	3.654135338
				207	18	stroke 2	
				335	128	stroke 3	
				486	151	stroke 4	

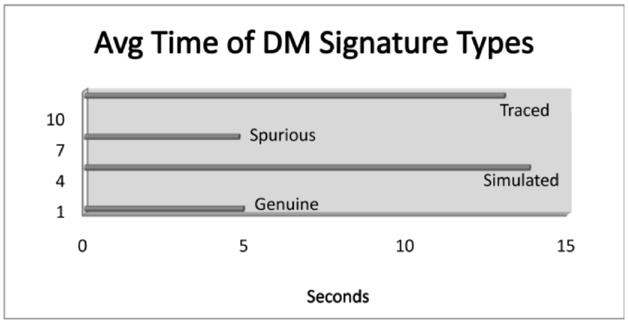
Figure 27. An example of the data collected for each signature plotted in this study.

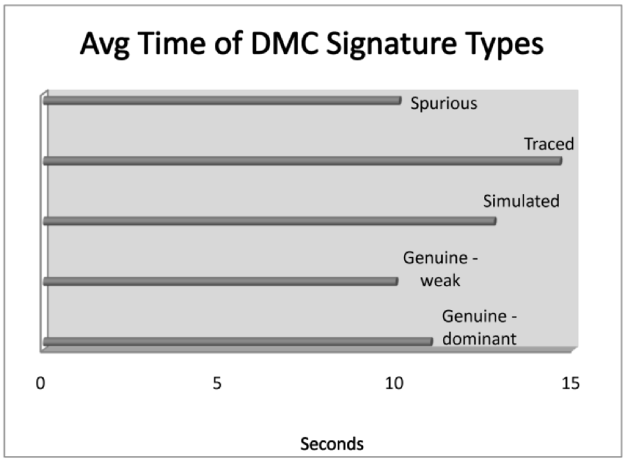
The average time of execution for each signature type was also calculated as well as the difference between the fastest and slowest signature execution. An example of this information is provided in Figure 28:

Sig #	Name	Total # Data Pairs	# Strokes	Time = Total # Data Pairs / 1/133 sec.	Avg Time	Diff b/w Fastest & Slowest Time
K-13-1	DM	576	4	4.330827068		
K-13-2	DM	706	4	5.308270677		
K-13-3	DM	685	6	5.15037594		
				14.78947368	4.929825	0.977444
KS-22-1	DM simulated by WJF	1579	4	11.87218045		
KS-22-2	DM simulated by WJF	1896	4	14.2556391		
KS-22-3	DM simulated by WJF	2035	5	15.30075188		
				41.42857143	13.80952	3.428571
KSP-19-1	DM spurious by AK	667	3	5.015037594		
KSP-29-1	DM spurious by CMK	608	5	4.571428571		
				9.586466165	4.793233	0.443609
KT-24-1	DM traced by WJF	1722	5	12.94736842		
KT-24-2	DM traced by WJF	1951	4	14.66917293		
KT-24-3	DM traced by WJF	1526	6	11.47368421		
				39.09022556	13.03008	3.195489

Figure 28. Data was collected and compared on all associated signature types. For instance, the above chart compiles data on genuine DM signature samples as well as simulated, spurious, and traced DM signatures.

This data was then graphed to see if patterns developed. Following are copies of these graphs.





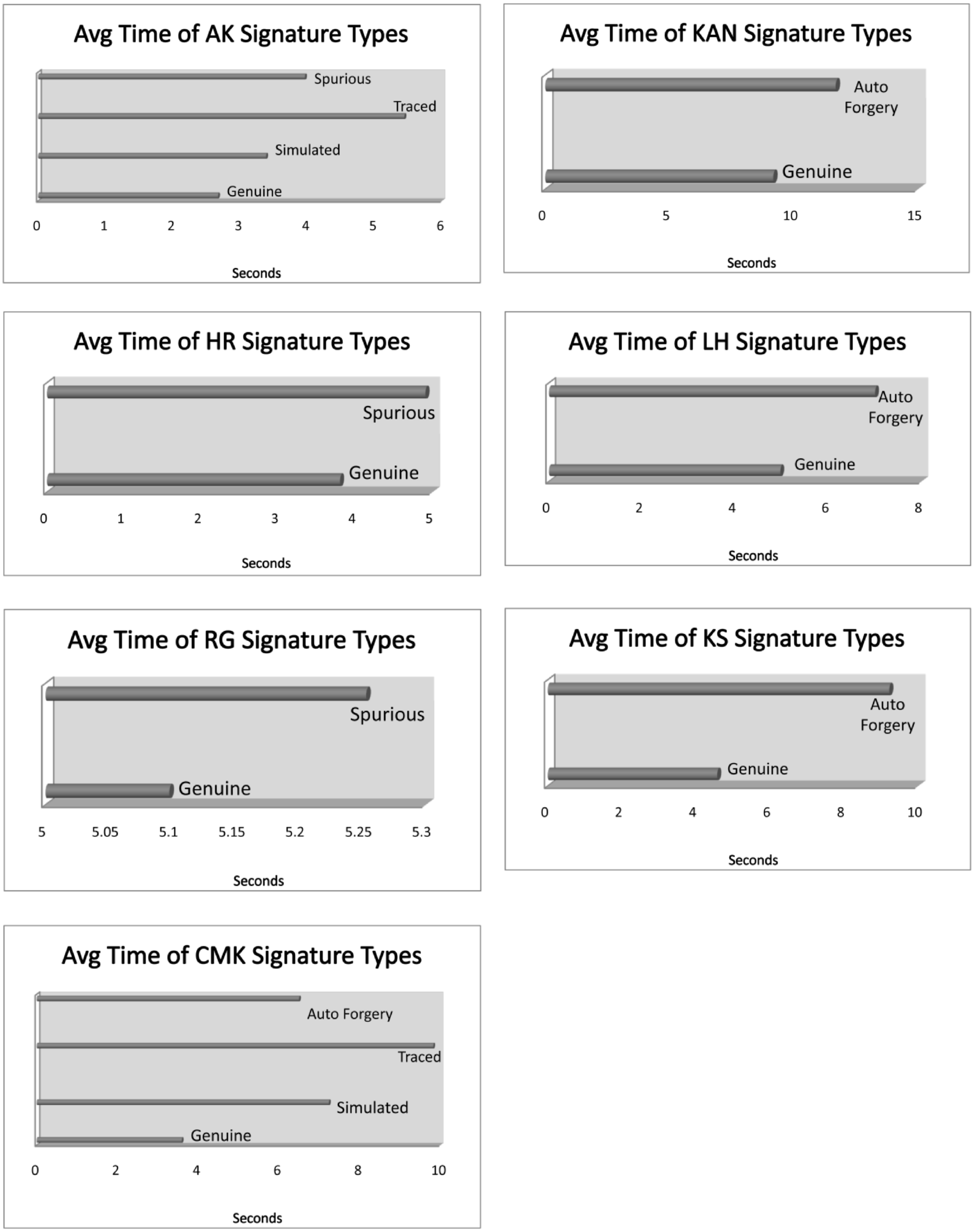


Figure 29. Graphs illustrating the speed of execution of genuine, non-genuine, and distorted signatures.

These graphs prove true the long-held tenets of forensic document examination that simulated and traced signatures are executed at a slower speed than genuine signatures. The same is demonstrated for auto forgery. However, proving another long-held tenet, the same could not be said for spurious signatures; these signatures were sometimes written as speedily as genuine signatures. I observed that the speed of the spurious signature often depended on the writer – whether they conscientiously wrote each letter in the name or if they scrawled the signature.

During analysis, the maximum distance (highest vertical axis value) was noted on each acceleration/deceleration plot and then entered into a spreadsheet. Average maximum distance was then calculated. The average maximum distance of different signature types was then graphed and analyzed to see if a pattern emerged.

No clear pattern was observed. For this reason, comparisons of the *maximum distance alone* would not yield reliable results in an examination of acceleration/deceleration plots. Rather, analysis of the variation in distance should be conducted in the same fashion as a study of intra- and inter-letter proportions, and should be analyzed throughout the plot.

Conclusion

In the 2nd Edition of Scientific Examination of Questioned Documents, "rhythm" is defined as "…regularity in the curvature of the writing, taking into account spacing characteristics and the graphic patterns established as the pen repeatedly returns to the baseline. The skilled writer will usually produce handwriting that is pleasing to the eye and that contains a recurring series of stress and impulse movements throughout… Writing that is irregularly spaced or that contains erratic movements exhibits poor rhythm due to abnormal contraction and release movements produced by the hand. Consequently, poor rhythm is one feature that distinguishes freely executed handwriting from the crude product of a tracing or freehand simulation." (p.56)

In essence, acceleration/deceleration plots are graphic representations of a writer's rhythm. As one of the elements considered during a wet signature examination, it should be equally analyzed in the examination of electronic signatures. While I would advise against conclusions based solely on comparisons of acceleration/deceleration plots, these plots contribute greatly to electronic signature examinations, especially when analyzed in conjunction with the dynamic data and the plotted signature graph.

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