The Importance of Line Width Measurements in Discriminating Between Pencil Types

Chris Anderson, BSc[1], Sigurbjorg Gudlaugsdottir, M App Stat,[2] and Julian Leslie, PhD[3]

[1] Chris Anderson & Co Pty Ltd, Forensic Document Examiners, P.O. Box 2778 Carlingford, NSW 2118, Australia
[2] Lecturer in Statistics, DEFS, Macquarie University, Sydney, NSW 2109, Australia
[3] Associate Professor, Statistics, DEFS, Macquarie University, Sydney, NSW 2109, Australia

Various graphical and statistical analyses were undertaken to investigate whether, in a specimen of pencil writing, it was possible to determine if the writing instrument was a mechanical pencil or a wood-cased pencil. A further consideration was whether it was possible to determine the diameter and/or softness of the lead for mechanical pencils. Ten writers provided samples using each pencil type, together with 4 levels of softness. The maximum width for a character was the measurement of interest. It was found that for particular soft leads it was possible to distinguish diameters of mechanical pencil leads. Distinguishing between mechanical and wood pencils depended on the softness and the diameter of lead. Small diameter soft leads in mechanical pencils were easily distinguished from wood pencils. In the remaining cases, differentiation between mechanical and wood-cased pencils was not readily established.

Introduction

This study arose from a case where it was suspected that 6 words, written in pencil, were added at a later time to an existing pencil entry in a diary. The entry read:

Ronnee left work at 9-30 am. Take Holidays?
Find out who she told
Dave rang George quit.

It was further alleged that a mechanical (or propelling) pencil was used to write these entries. There was no dispute that all the entries were written by the same person. The questioned text was: *Find out who she told* and the word *quit.* Initially, no permission was given to remove samples of the pencil writing for testing of the elemental components of the pencil lead using a scanning electron microscope (Cain, Cantu et al., 1978). The only alternative then was a physical examination.

The purpose of this pilot study was to determine whether the mean maximum width (MMW) of a pencil line (or quantities derived from them) could be useful in deciding whether a mechanical pencil or a wood pencil had been used. If apparent that a mechanical pencil had been used, does MMW aid in the determination of the actual width of the pencil lead used? If revealed that the MMW pencil lines provide useful discriminating information, then such measurements could provide evidence as to whether similar or different pencils were used to write the added entries. Also, the study considered the influence (if any) of gender and handedness on the maximum line width. The writing surface factor (and the effect that this may have on resulting pencil width) was not taken into account.

In the published literature, no reported instances were found involving the usefulness of taking measurements of the maximum line width (Mitchell, 1935; Harrison, 1966; Hilton, 1982; Masson, 1986; Petroski, 1990; Ellen, 1997). It was interesting to note that the only reference to using the line width produced by writing instruments for discrimination was by Albert S. Osborn (1910, 1929) in reference to discriminating between the work of different nibbed pens. Osborn used the minimum width of the line in his assessments.

The basis for using maximum line width was that this measurement should be close to the diameter of the pencil lead (augmented a little to accommodate the fact that the pencil will be held at an angle to the page that is smaller than 90 °). Further, in extended pieces of writing, the maximum width must be constrained by the diameter of the lead, and it should be possible to distinguish wood-cased pencils from mechanical pencils on the grounds that wood-cased pencils should occasionally have maximum widths exceeding that possible by the mechanical pencil. It is these extreme values that were of particular relevance. Further, for a given pencil diameter, a softer pencil lead tended to generate larger maxima, or at least a higher average maximum width.

Another feature of relevance was the variability of the MMW. There was limited scope for variability with the smaller diameter mechanical pencils, whereas the larger diameter mechanical pencils had the greater scope. The wood-cased pencils had the greatest scope. One way to adjust for this was to divide the maximum widths by the diameter of the mechanical pencil used. Additionally, it was expected that for mechanical pencils of a given diameter, the softer the lead, the greater the variability.

Method and Materials

A statistical analysis was undertaken using the maximum line width of the pencil lines. Thirty-three measurements were taken on the questioned text and 59 on the specimen text. A stereomicroscope fitted with a graticule was used to measure this width. For the analysis, it was hypothesized that the maximum width of the line would be the best indicator of the actual width of the lead of the pencil. Further, if there was a statistical difference between the MMW of the questioned and specimen entries, then this would be an indicator that the MMW of the pencil lines originated from different pencils.

Based on a 2-sample t-test, there was no statistical difference between the questioned and specimen MMW of the pencil lines ($t = -1.53$, *p–value* $= 0.133$). A box-plot (Figure 1) of the MMW of the questioned ($\mu = 0.41$ mm) and specimen ($\mu = 0.45$ mm) pencil lines highlighted the lack of difference between the means. Based on this result, it was concluded that there was no statistical difference between the MMW of the questioned and the MMW of the specimen pencil lines and, therefore, no evidence to support a conclusion that different pencils had been used to write these entries. Any observed differences were readily explained as random variation.

It should be noted that the box-plot has a central rectangle with 2 "whiskers," 1 at each end of the rectangle. The position (on the vertical axis) of the bottom of the rectangle corresponds to the lower quartile (25% of the observations fall in the value below), and the top corresponds to the upper quartile (25% of the observations fall in the value above). The upper whisker extends to the largest value and does not exceed length 1.5 x 1 where 1 = interquartile range = length of the rectangle. Each whisker points beyond a distance of 1.5 x 1 above the top of the rectangle, individually identified as a dot or asterisk. The whisker and points at the lower end of the rectangle are represented in a completely analogous way. There is usually a horizontal bar with the rectangle that represents the median (50% of observations are below and 50% above), and there may be a dot corresponding to the average of the observations.

A suitable experimental design was developed to investigate various ideas. Commonly available mechanical pencils of differing diameters were used, together with a combination of leads of different hardness and softness (Blau and Gardner, 1996). Also used were 4 wood-cased pencils, each with a different hardness. Specimen writing was taken from 10 subjects. The writing was supported on a writing pad to provide optimum writing surface. It was believed that a very hard surface such as a desktop would limit the maximum stroke width.

Each writer provided pencil writing samples of 17 words written in 2 parts (A and B). Part A writing consisted of the text, *Ronnee left work at 9-30 am. Take Holidays? Dave rang George.* Mechanical pencils were used by each writer for Part A, and fresh lead was provided. Wood-cased pencils were used for Part B, and the lead was sharpened using a manual pencil sharpener. Part B text consisted of, *Find out who she told quit*. It appeared that on the questioned document a sharpened (or newly broken) pencil was used for writing the Part B text. Therefore, the lead was taken out of the mechanical pencils' housing and reversed prior to writing Part A. In the case of wood-cased pencils, the lead was resharpened prior to writing Part B.

Mechanical pencils with nominal widths of 0.35 mm, 0.5 mm, 0.7 mm, and 0.9 mm were used along with a range of "Tradition" wood-cased pencils manufactured by Staedtler. For comparison, it was noted that wood-cased pencils had a lead diameter of 2.0 mm. For each pencil type, 3 or 4 different hardness and/or softness of leads were used. Unfortunately, it was not possible to obtain leads of the same hardness for each pencil type, as each writer was required to write Parts A and B text 16 times using a pencil type/hardness combination (Table 1). Aside from pencil use, the only requirement placed on the writers was to use

	0.35 MP	0.5MP	0.7MP	0.9MP	WCP
2B		X	X	X	X
B	X				X
HB	X	X	X	X	X
2H	X	X	X	X	X

Table 1. The hardness/softness of the leads used for mechanical pencils (MP) and wood-cased pencils (WCP).

Pencil Type (PType)		Hardness/Softness (Soft)	
1	0.3	1	2B
2	0.5	2	B
3	0.7	3	HB
4	0.9	4	2H
5	WCP		

Table 2. Codes used to identify the main variables used in the analysis and graphs.

either a cursive writing or script printing or a combination of the writing styles but not in an uppercase or block printing writing style.

Measurements of the maximum line width for each letter of Parts A and B text were made using a stereomicroscope fitted with a measuring graticule. Three university students were employed to undertake these measurements. The instructions were to select the greatest or widest line width for each letter in the text, making sure that an overwritten or retraced stroke was not measured. Letters that contained curves (such as the letter "o") had the measurement taken at the width perpendicular to the tangent (the point of greatest width on the curve).

The measurements for the line widths for each writer were entered onto a spreadsheet that included information as to gender, handedness, pencil type, and lead hardness. Except for the width measurements, all other variables were categorical variables. However, later in the analysis, lead diameters were handled as a ratio scale variable. These spreadsheets were then collated into a single data sheet for statistical analysis. A total of 11,774 line width measurements were made for the 10 writers. Clearly, some sort of automatic computer graphics procedure would be needed for this method to be practical. Codes were developed to identify the categorical variables used in this analysis (Table 2).

A preliminary graphical exploration of data was carried out using the statistical software package MINITAB, a package widely used in business and education. Based on the information obtained from the preliminary analysis, a standard regression model was selected to represent the data (Moore and McCabe, 2003).

Results and Discussion

As writer-to-writer variation was very important, a graphical summary of each writer was obtained. If all writers were to be combined and the results averaged, no useful conclusion could be reached. The measurements were numbered sequentially from written character to character in the order in which the writing took place, the same order (increasing pencil diameter 0.3 mm, 0.5 mm, etc., with increasing hardness for each pencil diameter) being used for all writers. The graphs of the maximum character width against measurement number were documented for just *Writer A* (Figure 2) and *Writer B* (Figure 3). It should be noted that similar features were found in the writing of other study participants. The graphs were coded according to pencil softness and grouped by mechanical pencil diameter size, followed by the wood-cased pencils. There was too much information in these graphs to allow comparison between writers or to detect anything other than gross features.

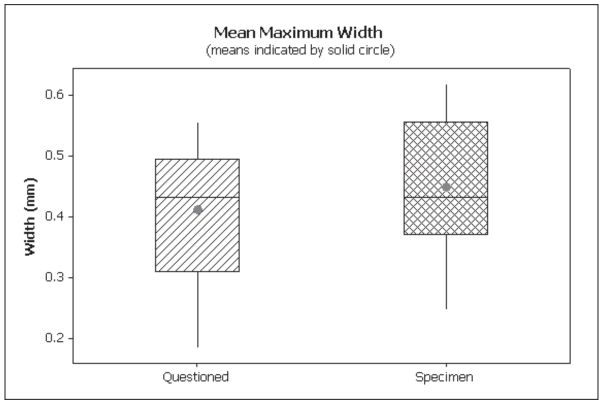


Figure 1. The box-plot has a central rectangle with 2 "whiskers," one at each end of the rectangle. The position (on the vertical axis) of the bottom of the rectangle corresponds to the lower quartile (25% of the observations fall in the value below), and the top corresponds to the upper quartile (25% of the observations fall in the value above).

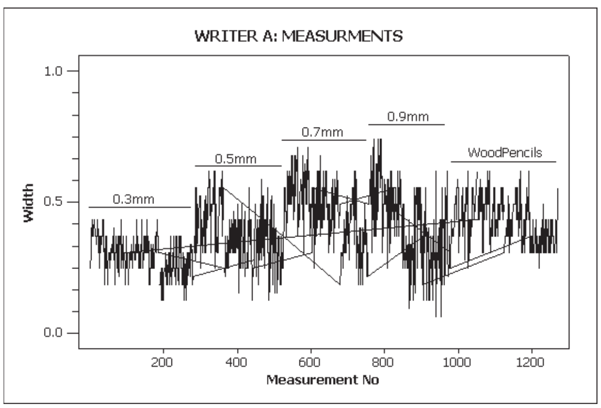


Figure 2. Maximum line width measurements for *Writer A* with measurement number on the x-axis.

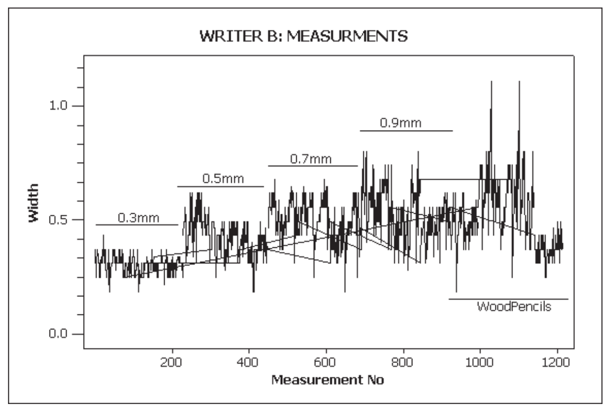
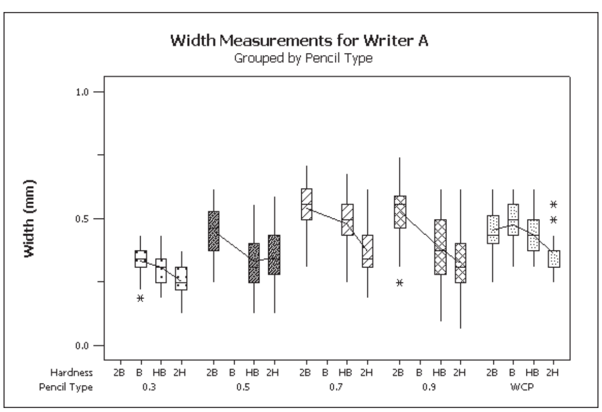
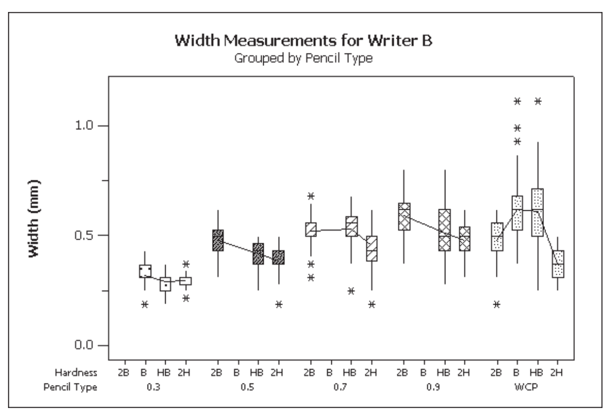
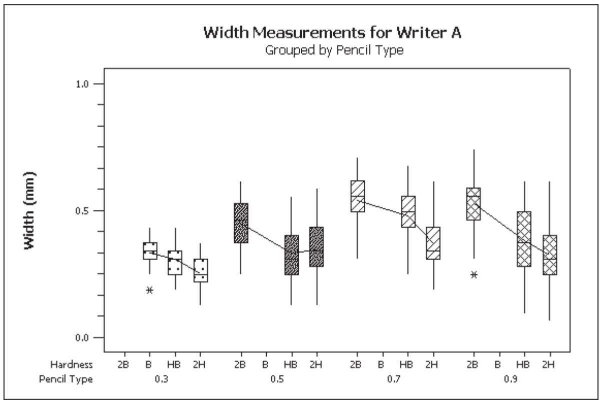


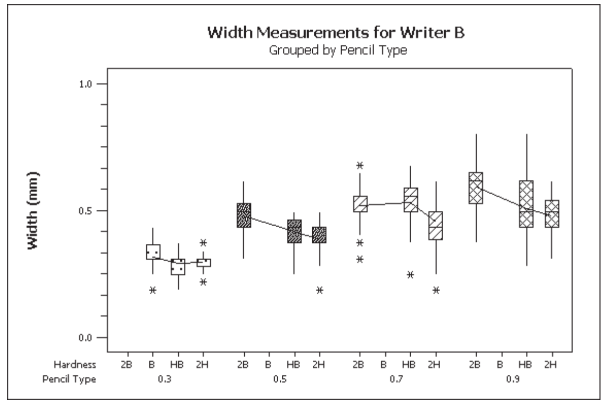
Figure 3. Maximum line width measurements for *Writer B* with measurement number on the x-axis.



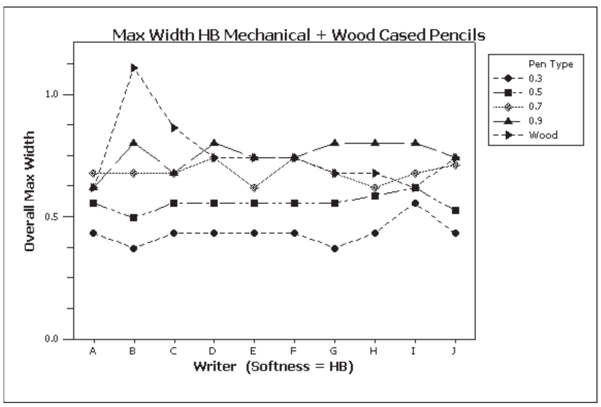


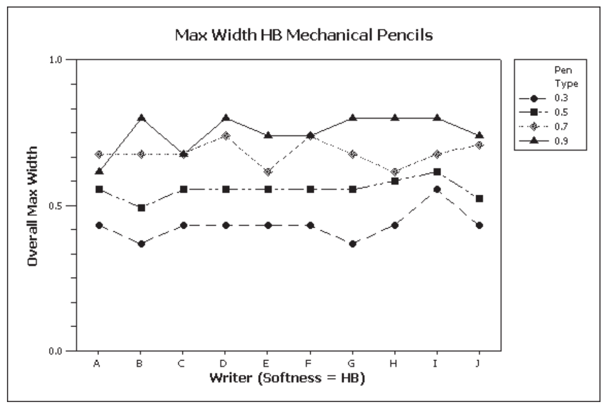
Figures 4 and 5. Width measurements for *Writers A* and *B* grouped by pencil type (including wood-cased pencils). The lines linking the means of various softness noted in each pencil type decreased, with the exception of wood-cased pencils (the final set of 4 box-plots on the right in Figures 4 and 5).



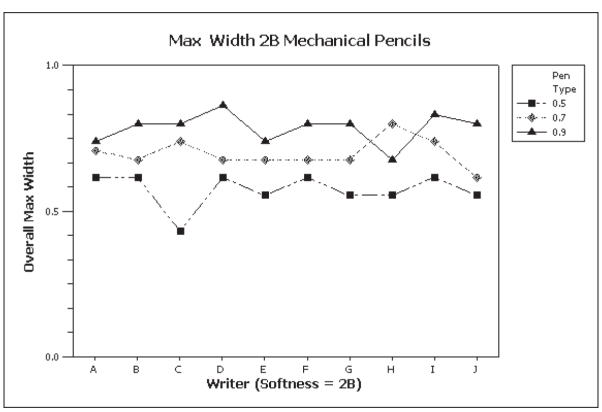


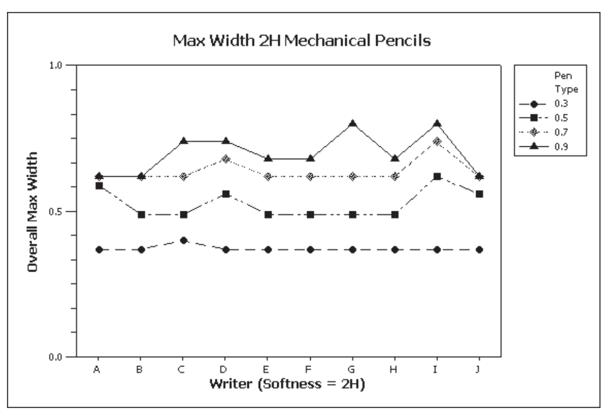
Figures 6 and 7. Width measurements for *Writers A* and *B* grouped by pencil type (without wood-cased pencils).





Figures 8 and 9. The wood-cased pencil data was mixed up with the mechanical 0.7 mm and 0.9 mm data. The plot was rerun without the wood-cased pencil data. This is seen in Figure 9 (right), where the data now consist only of the mechanical pencils. The feature to note is that, except for *Writer A*, all maxima were in the order: 0.9 mm the largest, followed by 0.7 mm, 0.5 mm, and finally 0.3 mm. This pattern was repeated in other pencil softness.





Figures 10 and 11. *Writer H* (Figure 10, left) has the 0.7 mm maxima exceeding the 0.9 mm maxima. In Figure 11 (right), note again the separation of the 4 graphs for *Writer I*. Also, *Writer I* tended to write at a smaller angle to the page than the other writers and so produced maxima that exceeded those of other writers. This tendency was apparent in the other figures.

Two sets of 10 (one corresponding to each writer) grouped box-plots were produced: 1) a set of box-plots that have the data grouped by pencil type and include wood-cased pencils, and 2) the same data as in 1 but without the wood-cased pencils as comparisons between mechanical pencils. The 2 sets of box-plots, just for *Writers A* and *B* (Figures 4 and 5), illustrated the effects of interest; i.e., effects that were evident to a greater or lesser extent in the other plots. The lines linking the means of various softness noted in each pencil type decreased, with the exception of wood-cased pencils (the final set of 4 box-plots). This effect was expected because, as the lead softness decreased (i.e., the hardness increased), the mean widths decreased for the various mechanical pencil types.

Once wood-cased pencil box-plots were removed (Figures 6 and 7), there was a decrease in mean width as pencil hardness increased (indicated by black lines linking the box-plots). As pencil diameter increased, there was a tendency for the mean width to increase for a given softness (less visible in *Writer A* than in *Writer B*). That both these effects were present for all writers can be demonstrated in a statistical analysis of the data whereby straight lines were fitted with a common gradient to the 3 means within each pencil type and, as well, fitting a straight line to the overall means of the 4 pencil types (Appendix 1).

It was also observed that for each level of softness, the maxima for each box-plot (the uppermost end of the box-plot; sometimes this is an asterisk) increased across pencil types. This was demonstrated by identifying the maxima of all observations for each of the 12 box-plots and plotting them for the 10 writers (Figures 8 and 9).

In a series of graphs, there was a clear separation (in almost all cases) of mechanical pencil sizes across for the 10 writers in the special case when the softness of the mechanical pencil was known. The key variable of interest was the overall maximum of the widths. Each writer had just 1 overall maximum width for each pen type and lead softness. In other words, each writer generated 16 overall maxima—3 for each of the 4 mechanical pencil sizes and 4 for the wood-cased pencils. The confounding influence of wood-cased pencils was present in width data for most softness; therefore, the wood-cased pencil data can be removed from discussion in all but the first plot. The wood-cased pencil maxima included in the first plot (Figure 8) illustrated the contaminating effect in the particular case of HB pencils for which all 4 mechanical pencil diameters were available as well as wood-cased pencils. The wood-cased pencil data is mixed up with the mechanical 0.7 mm and 0.9 mm data. The plot was rerun without the wood-cased pencil data (Figure 9). The feature to note is that, except for *Writer A*, all maxima were in the order of: 0.9 mm largest, followed by 0.7 mm, 0.5 mm, and finally 0.3 mm. This pattern was repeated in the other pencil softness.

Writer H had the 0.7 mm maxima exceeding the 0.9 mm maxima (Figure 10). Note again the separation of the 4 graphs for *Writer I* (Figure 11). Also, *Writer I* tended to write at a smaller angle to the page than the other writers and so produced maxima that exceeded those of other writers. This tendency was apparent in the other figures. Softness B was not included, as there was only 1 mechanical pencil with that softness (0.3 mm).

Conclusions

It was shown that for the 0.35 mm, .07 mm, and 0.9 mm mechanical pencils, the maximal width for the somewhat limited amount of writing in this experiment allowed reasonable discrimination between the 4 pencils, at least within each writer's writing. However, it was different across writers. The maximal width was likely to be useful when there was writing by the 1 writer using different diameters with 1 lead softness.

The variability of the measurements (as indicated by the length of the rectangular box part of each graphic in Figures 6 and 7) can be seen to have a tendency to decrease within each group of 3 box-plots of the 1 pencil type when moving from the softer lead to the harder lead. Although picked up in a statistical analysis of the data, this is not a particularly strong effect as it was clear for some writers but apparently absent in others.

This exercise was a pilot study intended to indicate promising directions for further investigation. Maximal width measurements have been shown to distinguish different mechanical pen diameters for a given level of softness. The smaller diameter mechanical pencils—0.3 mm and 0.5 mm—already differ quite noticeably from wood-cased pencils. However, more extensive writing may be required to distinguish between wood-cased pencils and mechanical pencils with larger diameters. This would generate the bluntness required to produce really extreme widths in wood-cased pencils that could not have been obtained from a mechanical pencil. To this end the authors are currently looking at replicates of the London Business Letter written by the 10 writers using the same selection of mechanical and wood-cased pencils (Osborn, 1929).

The question of whether there was evidence of differences in width measurements due to gender and handedness was also considered. It was not possible to obtain a sufficiently large sample to say much that is definitive on this matter, there being only 5 females and 4 left-handers. This is an insufficient sample size from which to draw any serious conclusions.

References

Blau, P. J. and Gardner, J. K. (1996). Tribological Characters of Graded Pencil Cores on Paper. *Wear* 197, pp. 233-241.

Cain, S.; Cantu, A., et al. (1978). A Scientific Study of Pencil Lead Components. *Journal of Forensic Sciences*, Vol. 23(4), pp. 643-661.

Ellen, D. (1997). *The Scientific Examination of Documents: Methods and Techniques*. 2nd ed., London; Bristol, PA: Taylor & Francis.

Harrison, W. R. (1966). *Suspect Documents: Their Scientific Examination*. 2nd Impression with Supplement. London: Sweet & Maxwell.

Hilton, O. (1982). *Scientific Examination of Questioned Documents*. Revised ed., New York: Elsevier.

Masson, J. F. (1986). Pencils. 38th Annual/Meeting of the American Academy of Forensic Sciences, New Orleans.

Mitchell, C. A. (1935). *Documents and Their Scientific Examination*. London: C. Griffin & Company Limited.

Moore, D. S. and McCabe, G. P. (2003). *Introduction to the Practice of Statistics*. 4th ed., New York: W.H. Freeman and Co.

Osborn, A. S. (1910). Chapter X - Writing Instruments. *Questioned Documents.* Rochester, NY: The Lawyers' Co-Operative Publishing Co., pp. 154-167.

Osborn, A. S. (1929). Chapter IV - Standards of Comparison. *Questioned Documents*. 2nd ed., Montclair, NJ: Patterson Smith, pp. 25-38.

Osborn, A. S. (1929). Chapter XI. Writing Instruments. *Questioned Documents*. 2nd ed., Montclair, NJ: Patterson Smith, pp. 151-166.

Petroski, H. (1990). *The Pencil. A History of Design and Circumstance*. New York: Alfred A Knopf, Inc.

Appendix A

The statistical software package MINITAB was used to analyze the widths for mechanical pencils using covariates SoftMech—hardness of mechanical pencil leads (1=2B, 2=B, 3=HB, 4=2H) and MechPWdth (widths 3.5 mm, 5 mm, 7 mm, and 9 mm). The idea is to model the drop in widths as hardness increases for a particular diameter and the increase in width as diameter increases.

General Linear Model: WidthMech versus WriterMech

```
Factor      Type    Levels  Values
WriterMech  random      10  1, 2, 3, 4, 5, 6, 7, 8, 9, 10

Analysis of Variance for WidthMech, using Adjusted SS for Tests

Source                  DF    Seq SS   Adj SS   Adj MS        F      P
WriterMech               9      7.40     0.99     0.11    14.72  0.000
SoftMech                 1     13.85     9.39     9.39  1261.72  0.000
MechPWdth                1     45.12    45.37    45.37  6094.09  0.000
WriterMech*SoftMech      9      1.51     1.65     0.18    24.68  0.000
WriterMech*MechPWdth     9      1.59     1.59     0.18    23.71  0.000
Error                 8826     65.70    65.70     0.01
Total                 8855    135.17

S = 0.0862802   R-Sq = 51.39%   R-Sq(adj) = 51.23%

Term                   Coef   SE Coef       T      P
Constant               0.30     0.004   81.07  0.000
SoftMech              -0.03     0.001  -35.52  0.000
MechPWdth              0.03     0.000   78.06  0.000
SoftMech*WriterMech
          1          -0.024     0.002  -10.65  0.000
          2          -0.001     0.002   -0.21  0.834
          3           0.006     0.002    2.42  0.016
          4          -0.000     0.002   -0.15  0.881
          5          -0.003     0.002   -1.06  0.290
          6          -0.014     0.002   -5.62  0.000
          7           0.009     0.002    4.01  0.000
          8           0.021     0.002    8.40  0.000
          9           0.007     0.002    2.80  0.005
MechPWdth*WriterMech
           1         -0.014     0.001  -11.02  0.000
           2          0.004     0.001    2.76  0.006
           3          0.005     0.001    3.79  0.000
           4         -0.003     0.001   -1.92  0.055
           5         -0.003     0.001   -2.14  0.033
           6          0.005     0.001    4.05  0.000
           7          0.006     0.001    4.41  0.000
           8         -0.002     0.001   -1.17  0.241
           9          0.007     0.001    5.20  0.000
```

Note: With the massive F-values for the SoftMech and MechPWdth covariates, 2 variables were treated as ratio scale variables rather than categorical variables. The 1st interaction term allowed differing gradients on the softness of lead for each writer rather than insisting on the 1 gradient for all writers. The 2nd interaction term allows differing gradients on the pencil types (picking up the gradual increase in widths as the pencil diameter increases) for each writer rather than insisting on the same gradient for all writers. The conclusion from all this was that there is a strong negative gradient (-0.0277) for the softness (**i.e.,** as the hardness increases the mean width decreases for a given pencil type) and a strong positive gradient (0.065) for the pencil type (i.e., as the mechanical pencil diameter increases so does the mean width). The relatively small F-values for the interaction terms (particularly given the huge number of observations) means that interactions can more or less be ignored.