The objective static analysis of spatial errors in simulations

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Abstract. *The Pattern Evidence Analysis Toolbox software (Found, Rogers & Schmittat, 1994) has been specifically designed to take accurate spatial measurements from static handwriting traces including signatures. Forensic handwriting specialists in casework frequently encounter signatures of questionable authenticity. Some criticism has been levelled at this forensic field resulting from the lack of objective data used to draw conclusions regarding the authenticity of questioned signatures. In this study a range of spatial measurements of 200 known signatures, collected from 10 individuals, was compared to 140 forgeries of their signatures made by 14 forgers. It was found that the forgeries as a group did display significant numbers of spatial errors when compared to genuine signatures. The results indicate that measurement of spatial errors could be a source of information which can be used to discriminate between possible simulations and genuine signatures, and provide data on the types of errors likely to occur. Information obtained in this study has been used for the development of software (Found, Rogers & Schmittat, 1998), which may ultimately be practicable in the forensic environment.*

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1. Introduction

Forensic handwriting specialists frequently encounter cases involving questioned signatures. Harrison (1958), in his chapter on signature forgery, lists seven classes that suspect signatures may fall into. There are signatures which, upon examination, appear completely unlike the signatures that they are purporting to be. There are forged signatures of individuals that do not exist. There are traced signatures drawn onto documents using a genuine signature as a guide, while freehand simulations are drawn onto a document freehand. Then there are questioned signatures that are genuine and are disputed either as a result of the signature being obtained by trickery, the author honestly not believing that he wrote it, or those signatures where the genuine writer has modified the formation, usually for the purpose of denial at a later date. A not uncommon form of forgery that must be added to this list is where a genuine signature has been photocopied onto a document. The task for the handwriting examiner is to distinguish between the possible classes that a questioned signature may fall into.

The main technique used to distinguish between classes of questioned signatures in the forensic environment is based on visual indicators (see Found & Rogers, 1999, this issue). Detailed descriptions of the features that are assessed subjectively in the determination of the authorship of a disputed signature appear in most forensic texts on the subject (Conway, 1959; Harrison, 1958; Hilton, 1982; Osborn, 1929; Ellen, 1989). However, it has been argued by some (Huber & Headrick, 1990, 1999) that forensic handwriting examination cannot be considered as a scientific discipline without the incorporation of objective measurement techniques. Huber and Headrick (1990) state, “Our studies of handwriting for identification purposes have always taken into consideration some measurable features, such as size, relative heights, spacing, though the recording of the

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measurements has not been standard practice Until we do so we must accept the fact this area of our work does not meet the criteria of science." Totty and Hardcastle (1986) on assessing the 'SIGNCHECK' signature authentication system state that future systems "may produce information about signatures which could augment the information currently available to the document examiner." Clearly, there is some support for the incorporation of measurements into the existing comparison methodology.

There are many techniques available to the document examiner that measure handwriting. Potentially relevant software continues to come on line through advances in signature verification systems and optical character recognition research. For the forensic practitioner, however, the data produced does not necessarily provide clear answers regarding the *class* that a questioned signature may fall into. This is a result of both theoretical and practical considerations. In the casework environment, unlike the environment constructed for signature verification techniques, the examiner has to contend with usually limited amounts and qualities of both questioned and specimen material. In addition, the time period over which the material was produced may vary considerably. Theoretically, if it is found that a questioned signature is spatially dissimilar to a specimen group, then this does not imply that an individual other than the genuine writer wrote it. Consequently, the use of objective measures in signature comparisons will likely be limited to the stage in the method where a decision is made regarding whether the questioned signature is similar or dissimilar to the specimen material.

A promising technique to obtain objective measures of line quality from static images is being developed (Frank & Grube, 1998). The study reported here involves a technique that provides spatial consistency information only. It is an early work carried out prior to the development of computer software such as the 'Angular Differential' (Found, Rogers & Schmittat, 1997) and 'Matrix Analysis' (Found, Rogers & Schmittat, 1998). This study aimed to investigate only one type of signature, the freehand simulation, using the PEAT software (Found, Rogers & Schmittat, 1994). A simulated signature is one that has not been performed using the normal generalized motor program for the genuine signature. This may result from the use of a motor program by someone other than the genuine writer, or by the genuine writer using a different motor program. We will refer to the simulations in this study as forgeries, only because we know that they were written for the purpose of deception by individuals other than the genuine writer.

Simulations can be made under a variety of circumstances and on a variety of documents, which may make the act more or less difficult for the simulator. Many of the normal sources of variation in routine case examinations have been controlled. In this investigation we have chosen the *one-off* simulation as might occur at a transaction point. These simulations are produced on a specific document where the forger only has one attempt to reproduce it for the purpose of a deception. The forgers were, however, given unlimited practice prior to this attempt. In addition, the comparison material was comprised exclusively of requested signature specimens taken in one sitting. One would expect, therefore, on the basis of investigations of normal variations conducted by authors such as Evett and Totty (1985), that the normal range of variation in the signature would be unlikely to be captured fully.

The aims of the experiment were firstly to determine whether *transaction point* forgeries exhibited measurable spatial errors as compared with genuine signatures. Secondly, for the spatial errors detected, we aimed to determine which parameter type they were most likely to be associated with. Thirdly, our aim was to determine whether spatial errors could be a source of information which could be used to discriminate between possible simulations and genuine signatures.

2. Method

2.1 Participants

Ten volunteers from the Victoria Forensic Science Centre provided signatures and gave the experimenters permission for their signatures to be simulated and used in this study. For the purpose of the study, the providers of the genuine signatures will be referred to as victims. Fourteen staff members of the School of Human Biosciences, at La Trobe University participated as forgers.

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3. Material and Apparatus

3.1 Signatures

Twenty-five signatures, each executed on blank sheets of A4 paper with a ball point pen, were received from each of ten volunteers from the Victoria Forensic Science Centre. A random sample of three signatures from each volunteer was provided to the forgers to use as models.

3.2 Measurement technique

The spatial parameters of the genuine victim signatures and the simulated signatures were measured using PEAT software in conjunction with an image processing package (NIH Image version 1.57) on a Macintosh II computer.

Since handwritten images are relatively small, it was necessary to enlarge them before the scanning process. This was achieved using an enlarging photocopier. Images requiring analysis were enlarged to approximately fit across an A4 sheet of paper. A calibration grid accompanied each image through the enlargement process. The enlarged images and calibration grid were scanned into a computer and saved as PICT files. Once all the images had been scanned, they were processed using NIH Image software. This processing routine was carried out on the image to set the upper and lower grey scale limits that resulted in the image appearing as a complete and continuous line. Images were converted to a binary form by setting the image pixels to black and all other pixels to white. A skeletonization routine was applied that reduced the lines in the image to a thickness of one pixel. The processed images were saved in a MacPaint format (72 dpi).

4. Procedure

The forging aspect of this investigation was run as a competition over a period of approximately six months. A small prize was offered to the most successful forger, according to the spatial analysis, and the running scores were updated publicly as each new forgery was completed by the group. In all, 140 forgeries were collected from the subjects. Simulations were made on blank sheets of A4 paper. The following instructions were given to the forgers:

You have been provided with 3 signatures taken from each of ten victims whose signatures you wish to forge. The plan is that you intend to pass at ten different banks withdrawal slips bearing the forged signature of each of the victims. However, this particular banking organization has introduced new security measures. They only provide you with one blank document on which to produce the signature and the signature must be produced on banking premises.

Your task is to learn to perform each of the signatures. You can take as much time as you like to practise each of the signature formations. You must sign your signature only once on the official banking document provided. You therefore only have one chance to produce the final forgery of each of the ten victims' signatures. Since the signature must be produced in the vicinity of a banking official, you cannot trace the signature or use mechanical aids (eg. a photocopier).

You must adhere to the following criteria:

1. The signature must be a freehand simulation of the victim's signature being copied.
2. The signature must be written using a ball-point pen.
3. When forging on the official document, only one attempt can be made for each signature. You may have a copy of each of the victims' signatures beside you for reference.

Subjects practised each signature between 50 and 250 times before providing the one-off simulation on the "official banking document".

5. Data Analysis

Measurements

Two forensic handwriting specialists and one academic jointly decided the parameters to be measured and compared. Parameters for 20 genuine signatures were measured to obtain the range of variation of the specimen material. This was done on each of the victims' signatures prior to the collection of the forgeries. Measurements were made of the 14 forgeries per victim and between 2 and 5 of the remaining genuine signatures. These measurements were used for comparison with the range of variation in the specimen signatures. The parameter types and the abbreviations used to refer to them are given below.

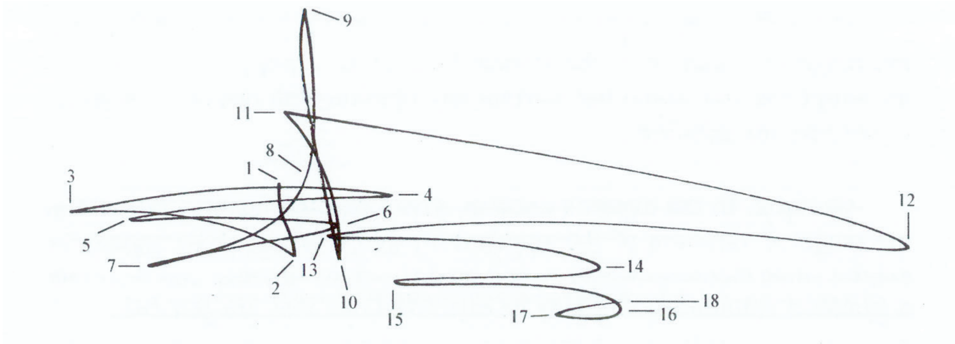

FIGURE 1. An example of a signature illustrating numbered feature points be tween which specific measurements were performed.

5.1 *Total line length (TLL)*. This is a measure of the curvilinear line length for the entire image.

5.2 *Total area (TAREA)*. This is a measure of the total area enclosed by the line trace forming the signature.

5.3 *Area of enclosed loops (LOOP)*. This is a measure of specific areas enclosed by the line trace. An example of a loop can be seen in the sig nature of Figure 1 between points marked as 16 and 17.

5.4 *Length of specified lines (SPEC)*. This is a measure of the line length between two specific feature points that can be visually identified. An example of this can be seen in the signature of Figure 1 between points marked as 11 and 15.

5.5 *Width (WIDTH*). This is a measure across the horizontal plane of the signature between two specific feature points that can be visually identified. An example of this can be seen in the signature of Figure 1 between points marked as 3 and 12.

5.6 *Diagonal (DIAGONAL)*. This is a measure across the diagonal plane of the signature between two specific feature points that can be visually identified. An example of this can be seen in the signature of Figure 1 between points marked as 9 and 16.

5.7 *Height (HEIGHT)*. This is a measure down the vertical plane of the signature between two specific feature points that can be visually identified. An example of this can be seen in the signature of Figure 1 between points marked as 9 and 10.

5.8 *Angle*. Two angle types were measured. Given that an angle is formed by three points in space, the ANGLE UP measurement was de fined as an angle where the middle point was taken at a feature that was at the apex of the signature. An example of this can be seen in the signature in Figure 1 between points marked as 7, 9 and 12. The ANGLE DOWN measurement was defined as an angle where the middle point was taken at a feature that was at the base of the signature. An example of this can be seen in the signature in Figure 1 between points marked as 3, 15 and 12. In both cases the first and last points from which the angle was constructed were in the medial plane of the signature, to the left and right of the signature formations.

For each parameter type listed above, the number of measurements taken for each signature varied according to the number of feature points that could be confidently identified. In general, no more than three measures of each of LOOP, SPEC, WIDTH, DIAGONAL or HEIGHT were taken for each of the victims' signatures.

6. The comparison method and calculating a spatial error score

The comparison method involved taking measurements of the same parameters for all the signatures of a victim and comparing them between the questioned and specimen groups of signatures. The range of variation for a particular parameter for the specimen group was deter mined. The measurement for this parameter for each of the victims' questioned signatures was then compared to this range. If the measured parameter of the questioned signature fell outside the range of the specimens, this parameter was called an error (with a value of 1) for this signature. In this way a spatial error score could be generated for each of the questioned signatures, relative to the range of variation in measurements for the specimen group. In this context there may be an error score not only for forgeries, but also for genuine signatures included in the questioned group.

Since only a small number of comparison measures were taken for each signature, it was necessary to devise a scoring scheme which amplified any spatial error associated with the forgeries. Trials of these scoring procedures yielded the following scoring types, the scores for which were added to yield a compounded error score:

6.1 *Raw score (RAW).* The raw score was calculated by counting the number of times a measurement taken from a questioned signature fell outside the range of variation for that measurement in the specimen group. This error score was expressed as a percentage of the total measurements taken.

6.2 *Ratio score (RATIO).* The ratio for each of the measures associated with specified line lengths or distance between two points measurement (eg. HEIGHT, WIDTH), was calculated for each of the questioned sig natures. The ratio score was calculated by counting the number of times a ratio taken from a questioned signature fell outside the range of variation for that ratio in the specimen group. This error score was expressed as a percentage of the total ratio measurements.

6.3 *Normalized Scores.* Since questioned signatures can be larger or smaller than signatures in the victim's specimen group, and yet still retain the relative proportions of features in space, we incorporated into the error score a calculation that would compensate for this reality. Normalization selectively scales the signature features according to an adjustment made by one or more of the parameters to the mean for those parameters in the specimen group. For example, for a particular specimen signature, the width deviation from the overall width mean in the specimen group was calculated. This factor was then multiplied through the remaining parameters (compensations were made for area measurements and angles were excluded) in the specimen signature group to yield a new set of specimen comparison measurement ranges. Each questioned signature, once parameters had been normalized to the new specimen width mean, was then compared, and a normalized error score calculated. For each questioned signature, the error score was expressed as a percentage of the total measurements taken. Normalization scores were calculated for normalizations associated with total line length (NTLL), width (NWIDTH), height (NHEIGHT), total line length and width (NTLL&W), total line length and height (NTLL&H) and total line length, width and height (NTLL,W&H).

7. Statistical analysis

The error scores for each of the questioned signatures were calculated by expressing as a percentage the proportion of measures where the questioned value fell outside the range of variation of the specimen group for each test as indicated above. The error scores for each test were added to produce a final error score (compounded error score). This error score for the forged signatures in the questioned group was then compared to the error score for the genuine signatures in the questioned group, using unpaired two tailed *t*-tests to determine whether the spatial errors of these signature types differed.

8. Results

The questioned signatures analyzed for each victim included 14 forgeries and 2 to 5 genuine signatures. The error scores for each of the questioned signatures for four victims are represented in Figures 2 to 5. The error scores for each test are shown, along with the compounded error score. The full range of raw, ratio and normalized scores were made for nine victims. For victim 10 (Figure 5), a reduced number of measurements were taken, as measurement points were difficult to isolate because of the open and rounded formation of the signature. The same forgery number (x-axis on the graphs shown in Figures 2 to 5) were used for a particular forger for each victim. Inspection of the scores shown in the figures indicates a good deal of variation between forgers, and variation within forgers for different signatures.

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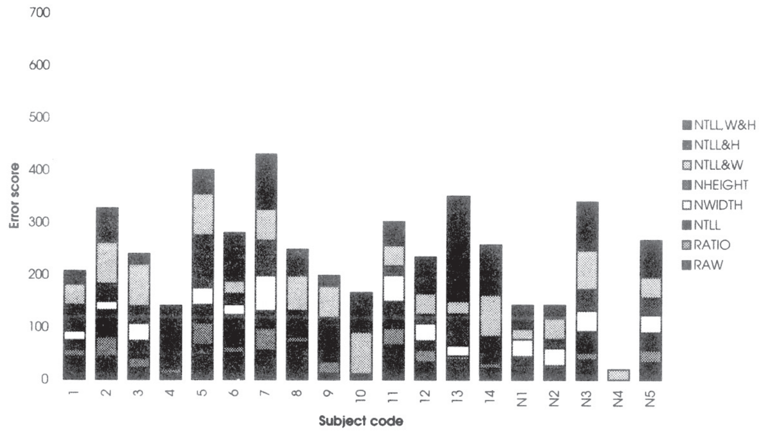

FIGURE 2. Compounded spatial error scores for the questioned signatures associated with victim 2. Forgeries are numbered 1 to 14 and genuine signatures numbered NI to N5. Maximum error score is 800. Error scores for the genuine signatures are not significantly different to the forgeries at p <.05.

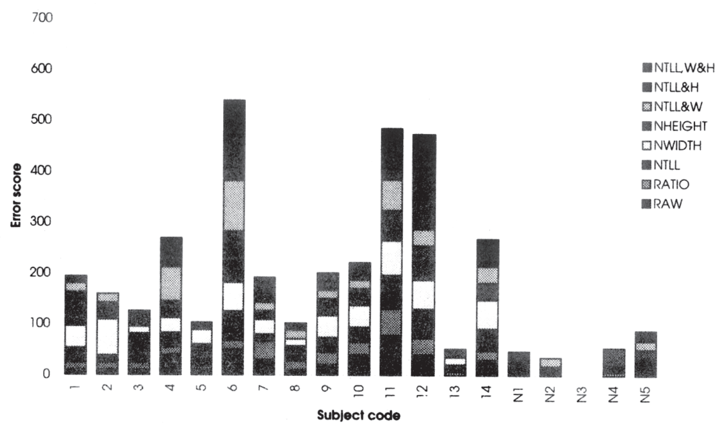

FIGURE 3. Compounded spatial error scores for the questioned signatures associated with victim 4. Forgeries are numbered I to 14 and genuine signatures numbered Nl to N5. Maximum error score is 800. Error scores for the genuine signatures are significantly different to the forgeries at p <.05.

The compounded error scores for the questioned genuine signatures were significantly less (p <.05) than for the forgeries for each of seven victims (Figures 3 to 5 are examples). For three victims (Figure 2 is an ex ample) there was no significant difference. When the forgery error scores for all victims' signatures were combined and compared to the error scores for questioned genuine signatures combined for all victims, there was a significant difference (at p<.05).

A comparison was made between the mean % spatial errors over all the victims' signatures, and the data types used to generate the compounded test score. In each case these data types could discriminate between the forged and genuine signatures in the questioned group (at p<.05). Figure 6 provides the mean percentage spatial error score for the questioned signatures for both forged and genuine signatures, versus the data test type used.

Figure 7 represents the proportion of occurrences, expressed as a percentage, where a particular parameter type was found to be in error in the forged signatures. WIDTH showed the greatest error, falling outside the range of variation for the specimen group in nearly 60% of cases, whereas TAREA had the lowest error(< 30%).

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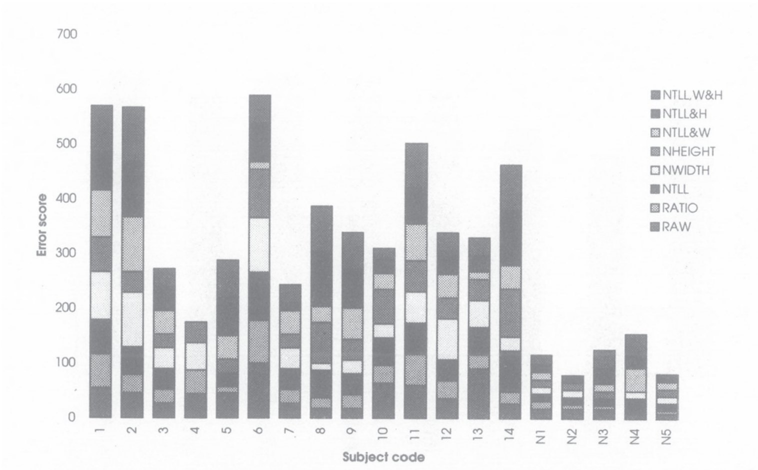

FIGURE 4. Compounded spatial error scores for the questioned signatures associated with victim 6. Forgeries are numbered 1 to 14 and genuine signatures numbered Nl to N5. Maximum error score is 800. Error scores for the genuine signatures are significantly different to the forgeries at p <.05.

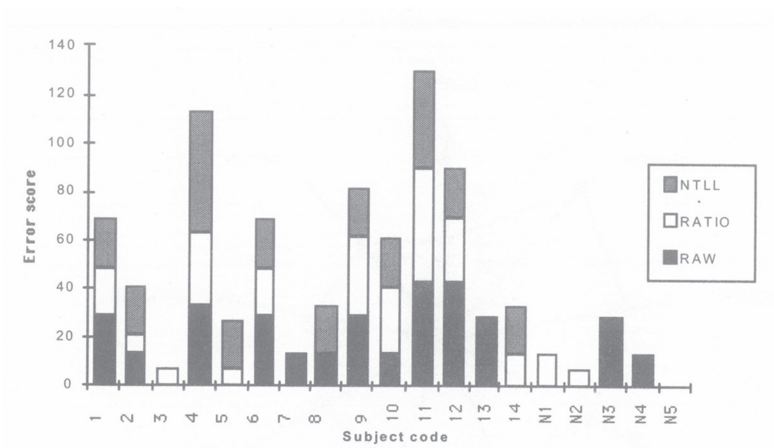

FIGURE 5. Compounded spatial error scores for the questioned signatures associated with victim 10. Forgeries are numbered 1 to 14 and genuine sig natures numbered Nl to N5. Maximum error score is 300. Error scores for the genuine signatures a re significantly different to the forgeries at p <.05

9. Discussion

Measurement strategies have been extensively used in the investigation of handwriting in the fields of motor control (eg Castiello & Stelmach, 1993; Phillips, Stelmach & Teasdale, 1991; Teulings, Thomassen & Van Galen, 1986; Wright, 1993), optical character recognition and signature verification (Han & Sethi, 1995; Leclerc & Plamondon, 1994), database searching systems both for forensic and signature authentication applications (Hecker, 1995) and to a much lesser extent in forensic handwriting examination (eg. Herkt, 1996; Philipp, 1996; Plamondon & Lorette, 1989). Many of these techniques rely on dynamic information which forensic specialists do not have direct access to. Research based on these dynamics, however, has proven directly relevant to forensic handwriting examination. Brault and Plamondon (1993) for example, investigated the relationship between signature complexity and the dynamic features associated with signature forgery. Van Gemmert and Van Galen (1996) used the dynamic investigative approach to illustrate the difference between forging and normal writing, using the relative power spectrum of the noise produced by writing

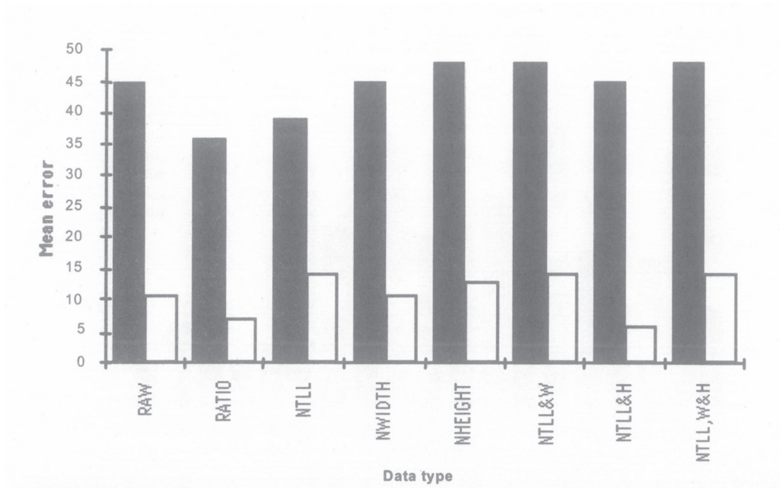

FIGURE 6. The mean% spatial error for the questioned signatures versus the data test type used. Forged signatures are represented by the black columns, and genuine questioned signatures are represented by the white columns. In each case the mean error for the forgeries is significantly different to the mean errors for the genuine signatures at p <.05.

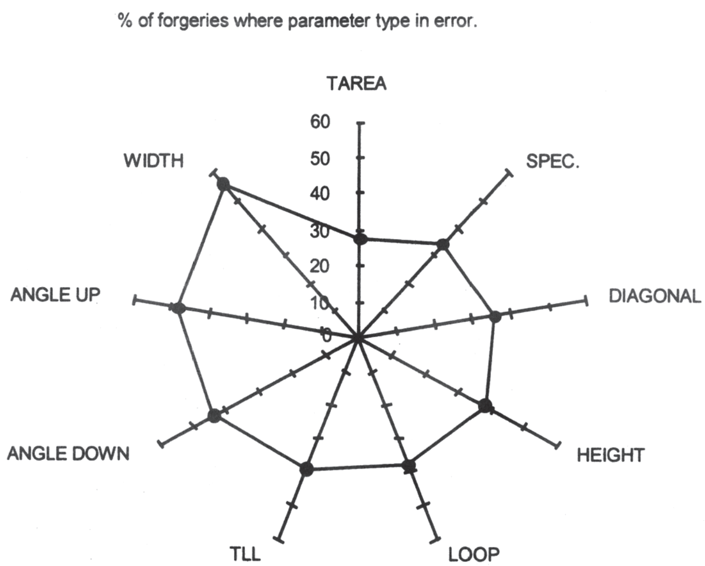

FIGURE 7. Number of occurrences in the forged signatures where the raw measurement of each parameter type fell outside the range of variation for the specimen group (expressed as a percentage).

under differing conditions. Van Gemmert, Van Galen, Hardy and Thomassen (1996) used a similar technique to investigate the dynamic characteristics associated with individuals disguising their writing. The advantage of data generated from studies of this type is that it is objective and can be tested.

Techniques based on research that can be incorporated into the forensic method for comparing handwriting traces, may ultimately be developed. The current study, although limited with respect to the number of measurement points compared and the method for selecting these measurement points, does provide significant support to the hypotheses that spatial disturbances can result from simulation behaviour, and that such disturbances can be objectively measured. Although line quality was not considered in this study, the vast majority of signatures suffered reduced line quality in addition to the spatial errors detected. In comparison, al though spatial errors were also detected in the genuine questioned images, no such line quality deterioration was evident. Due to a number of factors, compounding the error scores was found to more successfully illustrate the spatial error, as compared with the error calculated from raw measurements alone. For example, the questioned signature may have been proportionally consistent with the range of variation in the specimen group, but may have been performed to a scale not characterized by that group. Therefore, if we were to take the raw measurement alone, then a signature even slightly larger or smaller than the range of sizes in the specimen group would produce a large error score. In forensic science it is not unusual to observe writing behaviour that varies over time with respect to the size of the signature. This variation may even be due to the size of the space allocated to the signer on the document. Raw measurements alone, therefore, may produce an unrealistic picture of the spatial consistency. Ratio scores compensate for any error in the raw score due to this factor. The normalization scores highlight proportional differences in a different way. Normalization effectively standardizes all signatures being compared to a mean measure of a particular parameter or combination of parameters. This technique would likely be more effective should a much larger sample of measurements be taken. Nevertheless, the technique used in the current study appeared effective, despite the normalization process reducing the number of available comparison measurements.

If we compare the error scores between the grouped questioned genuine signatures and the grouped forgeries for each victim, we find that three of the ten victims' signatures, did not exhibit significant error scores (at $p < .05$). One victim had only two signatures in the questioned genuine group which were likely to effect any calculation of significance. The signature of victim 2 was pictorially quite variable, and manifested in two of the questioned genuine signatures, generating a high error score (Figure 2). Clearly, variation of this nature is likely a limiting factor in interpreting the significance of spatial error scores. The signature of the other victim was relatively simplistic and variable. Forgers, therefore, had less difficulty capturing the spatial character of the signature, which is reflected in the non-significant p value.

The balance of the victims' signatures did show a significant difference between the spatial error scores of the forgeries as a group, and the questioned genuine signatures as a group. Figure 4 is an example where most forgers had difficulty capturing the spatial features, as evidenced by the high compound error scores. The genuine questioned signature error scores were relatively low, indicating that the genuine writer was fairly consistent.

Of interest to us was the fact that, except for a few instances, there was an error score for the genuine, questioned signatures. This indicates that the 15 signatures in the specimen group did not provide sufficient range of variation to include all spatial parameters of the genuine signatures taken from an individual. While this was expected in most cases due to the nature of the signatures we used and previous observations (Evett & Totty, 1985; Totty & Hardcastle, 1986), it needs to be taken into account in future refinements of such objective techniques.

The individual's ability-to capture the spatial features of the signature being forged does vary to some extent, as can be observed by the differential height of the graphs showing the compounded error scores. Subject 13 is an example of a good forger of many signatures (see for example Figures 3 & 5) yet relatively poor with others (eg., Figures 2 & 4).

Although it was advantageous to use the compounded error scores for the individual signatures, the comparison between the mean percentage spatial errors over all the victims' signatures, versus the data types used to generate the compounded test score (see Figure 6), indicated the data types were useful on their own. In each case these data types could discriminate significantly between the forged and genuine signatures in the questioned group. The technique used is, therefore, able to discriminate between these forged and genuine signatures under the strict controls of this experiment.

The parameters measured from the writing trace (raw measurements) were considered individually to see how well particular parameters correlated with the forgery process in our population of subjects. This was done by comparing the number of occurrences in the forgeries where particular parameter appears to be relative measures of width. This does tend to make sense in that forgers, when drawing out the line, do so in a serial way. This may compromise their ability to reproduce spatial relationships separated in both time and space. The parameter least often found to be in error was measure of total area. It would appear that this results from the phenomena that this measure can vary quite markedly in response to slight differences in the movement of the pen. For example, if two portions of the line separated in time but not space did not intersect in one signature specimen but did in another, then the range of variation in the measure of that parameter could be very large. A large range of variation in a parameter provides the least difficulty for the forger to reproduce so that it falls within that range of the genuine signature group.

Experimental evidence (Leung, Cheng, Fung & Poon, 1993; Leung, Fung, Cheng & Poon, 1993; Van Gemmert & Van Galen, 1996) indicates that forgers concentrate on the spatial features of the handwriting they are producing in preference to capturing the dynamic features of the movement. Nevertheless, the results of the current study show that spatial relationships are difficult for individuals to capture accurately when forging signatures as a *one-off* simulation.

The analysis technique trialed here indicates that a number of aspects of the measurement of static signatures require development and improvement. Problems encountered include the significant amount of time taken, from scanning the images to generating a result, and the selection of appropriate measurement points. Examples of suitable solutions to these problems have been sought by the authors and have been reported (Found, Rogers & Schmittat, 1997; 1998). Future techniques should be aimed at incorporating spatial and line quality data together to objectively generate an error or consistency score. Handwriting specialists can then use this information at the stage where they determine whether the questioned image under examination is similar or dissimilar to the range of variation exhibited in the specimen material. Once this opinion has been reached, the expertise of the examiner can be used to focus on the appropriate propositions that explain the similarities and dissimilarities.

10. Conclusion

The technique employing PEAT software was successfully applied in this investigation to provide objective spatial error scores resulting from measurements of forged and genuine signatures. It was found that a significant number of spatial errors were made when individuals attempted to forge the signature of others. Techniques of this type have the potential in the future to offer forensic handwriting specialists methods to determine objectively those spatial features in signatures that are likely to reflect simulation behaviour. Future techniques should focus on characteristics associated with both space and line quality, to provide a useful scoring procedure.

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