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Examination of a Collection of Arabic Signatures

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Arabic is the national language of the 22 Arab States, where it is spoken and written by about 300 million people. Forensic document examiners are often required to examine Arabic signatures, but without the help of any reference library of signatures. This study generated a unique collection of signatures and multiple replicates on various occasions from 188 participants (128 male and 60 female). From this collection, 10 features common to all of the signatures were identified and used to examine the variation between signatures and generate quantitative data. The features (variables) selected included 3 measurable variables (i.e., height, length, height/length [H/L] ratio) and 7 features which could be classified according to a code (i.e., number of strokes, number of dots, direction of ending stroke, legibility of signatures, slant, starting position, and ending position).

Using frequency plots generated from 10 signatures produced on 1 occasion by all of the 188 participants, the distribution of data for each feature could be observed. These results indicated that only 15% of the applicants produced a legible signature, and legibility was shown to have a considerable influence on features such as the number of dots, number of strokes, slant, and ending and starting positions. Some unusual frequency distributions can be observed with several features (e.g., the number of dots, number of strokes and the H/L ratio), thus highlighting the uniqueness of some signatures. This form of visualisation also illustrated some unexpected results. For example, more participants produced right- as opposed to the normally expected left-slanted signatures, and a larger number of females were identified as using more strokes than males.

These frequency plots also confirmed that all the classified features and, to a lesser extent, the measurable variables were not normally distributed. Hence, a Mann-Whitney statistical test was used to determine if, for any feature, there were any significant differences between signatures produced by the male and female participants. Significant differences in data for 5 of the features can be identified; namely, number of strokes, number of dots, height, length, and H/L ratio. With the exception of the H/L ratio, a replicated study using a 2nd set of signatures produced by all the participants on another occasion gave virtually identical Mann-Whitney results, thus indicating the high degree of consistency of some of the selected features.

Introduction

Arabic is 1 of the 6 official international languages of the United Nations (Holes 1995). It is also the national and official language of the 22 Arab States, where it is the spoken and written means of communication of about 300 million native Arabic speakers (Smart 1992). Many non-Arabic Muslims speak and read Arabic because it is the language of Islam's holy book, the Quran, as well as extensive theological writings of that religion. With this extensive use of the language, forensic document examiners will have to examine Arabic signatures not only in the Arab States but also other countries.

Although there have been a significant number of studies on Arabic handwriting, these have mainly been based on computer optical character recognition (OCR) methods for verification and recognition (Burrows 2004). Many of the methods proposed have also been applied to the recognition and verification of Arabic signatures (Lam and others 1989, Darwish and others 2000, Ismail and others 2000, Kharma and others 1999). This latter study states that it provides a comprehensive database on Arabic handwritten words, numbers,

and signatures. However, only 350 documents produced by 70 people were examined. Again, Ismail and others (2000) examined only 10 signatures from each of the 22 participants. These sample sizes are far too small to provide a suitable reference collection from which frequency data can be generated. To the authors' knowledge, no major studies on Arabic signatures have been published, and no large reference collection of signatures has ever been produced. Without this background knowledge and data, this does present problems for forensic document examiners in providing supportive evidence in any examination of a signature. This study, therefore, initially set out to provide a reference collection of signatures and identify methods that could be used to provide quantifiable data. It was also the preliminary stage of a major study for developing quantitative objective methods for the examination of Arabic signatures that has been carried out by the authors which is to be published at a later date.

There have been many handwriting studies published on Western scripts, and comparisons in many instances have been based upon characters present in the text. This practice is also used by Arabic forensic document examiners when examining Arabic handwriting. However, a signature is considered to be a specialised form of handwriting and can be defined as a name or a mark that a person puts in a document to attest that he/she is the author or that he/she is ratifying its contents (Mathyer 1961). Hence, a signature or mark is personal, with its own particular combination of strokes and may contain no recognisable characters for comparison purposes. To overcome this problem and be able to quantify variations in signatures, we proposed a method whereby the signature is regarded as a picture which is made up of elements (features) which could be either directly measured or numerically coded. The other advantage of this proposed method was that if some, or even all, of a signature contained recognisable characters, document examiners with no knowledge of Arabic script would still be able to compare signatures.

To be able to provide meaningful reference and statistical data, it was recognised that sample size of the collection of Arabic signatures (number of participants) was an important parameter and must be large enough to satisfy the requirements for any statistical test that was to be performed. A sample size of 50 is generally accepted as a minimum for many statistical methods; and this was exceeded in this study, as 188 Arabic people agreed to participate. With 128 male and 60 female participants, this allowed statistical comparisons to be made between the male and female groups. All of these participants were required to provide 10 replicates of their signatures on 2 different occasions so that any study could be replicated.

Having established this collection of signatures, these were examined to identify any features common to all of the signatures that could be either measured (measurable variables) or classified by a numerical code (classified variables). This study initially identified the features that were selected and then set out to provide frequency of distribution and variability of the each feature in this collection of signatures. Using a Mann-Whitney statistical test (Daniel 1990), these data were also examined to establish if it was possible with any of the variables to discriminate between male and female signatures. All of the analyses were performed on 10 repeat signatures produced in 1 session by each of the 188 participants and subsequently duplicated by using another set of 10 signatures produced in another session. The results obtained from these studies, together with any limitations, are presented and discussed.

Materials and Methods

Ten signatures produced by each of the 188 participants in 2 different sessions were examined, with the signatures from 1 session being used initially. Signatures from the 2nd session were used in the duplicated study.

A total of the 10 most common features (variables) identified in the collection of 188 Arabic signatures were selected. To be able to examine these quantitatively, numerical values for each feature were required. In the case of 3 features (height, length, and height-to-length ratio), numerical values were obtained by direct measurement (measurable variables). A Vernier calliper was used to obtain these measurements in millimetres with an accuracy of 2 decimal places. Numerical values for the other 7 features (number of strokes, number of dots, direction of ending, legibility of signatures, slant, starting position and ending position) were obtained by applying a scoring system related to the number of forms of the feature. An additional null category was used for a signature not displaying a specific feature. The scoring systems used were as follows.

Number of Strokes

Numerical values for this feature were obtained by counting the number of pen lifts in a signature.

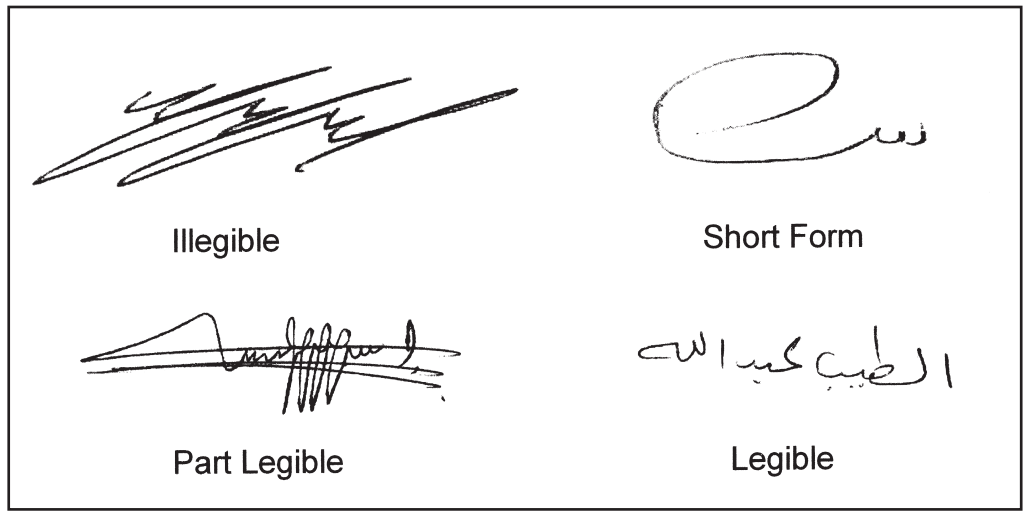

Figure 1. Examples of legibility and their classification. Note from these examples, which were produced by 4 of the participants, the legible signature is the only one where all the Arabic characters can clearly be identified.

The scoring categories for this feature were:

(Score 1) One stroke, where there were no pen lifts between strokes in the signature.

(Score 2) Two strokes, where there was 1 pen lift.

(Score 3) Three strokes, where there were 2 pen lifts, etc., up to (Score 8) for 8 strokes.

Direction of Ending Stroke

For this feature, 3 scoring categories based on the direction of the end stroke were used:

(Score 1) Downward, where the direction of the last letter or stroke was pointing downward.

(Score 2) Horizontal, where the direction of the last letter or stroke was showing no increase or decrease in slope.

(Score 3) Upward, where the direction of the last letter or stroke was pointing upward.

Legibility of Signature

For this feature, all of the signatures were examined and classified based upon 4 types and scored as follows:

(Score 1) Illegible or Stylish: Signature was neither decipherable nor readable.

(Score 2) Short Form: Signature contained the least number of pen movements and was more similar to an initial than a signature. These usually did not contain any recognisable Arabic characters and therefore was an illegible form of signatures.

(Score 3) Part Legible: Signatures had to be read in full to be able to decipher certain letters or particular words successfully. (Arabic document examiners consider that if more than 5% of a signature contains a legible Arabic character, then it is classified as being part legible.)

(Score 4) Legible or Ordinary Writing Text: Every single word or letter in the signature could be deciphered without the aid of the subsequent words or letters.

Examples of the different classifications of legibility of signatures are illustrated in Figure 1.

Slant of Signature

This feature was based upon which direction a signature was slanted, and the 3 scoring categories are as follows:

(Score 1) Left slant, where the slant direction of the signature was to the left.

(Score 2) Upright, where the slant leaned neither to the right nor the left.

(Score 3) Right slant, where the slant direction of the signature was to the right.

GENDER	AGE RANGE	FREQUENCY	% OF GROUP
Male	20-30	34	26.6
	31-40	39	30.5
	41-50	37	28.9
	51-60	18	14.1
Subtotal		**128**	
Female	20-30	30	50.0
	31-40	30	50.0
Subtotal		**60**	
Total		**188**	

Table 1. A summary of the numbers of male and female participants involved in the study and the numbers of these participants in each age group.

Number of Dots

For this feature the scoring system was based upon the total number of dots produced in a signature and ranged from 0 to 12. Note that when 2 dotted letters occurred togther, some writers substituted a dash (—); and for 3 consecutive dotted letters some writers used a carat (^).

Starting Position

This feature refers to the starting position of the 1st stroke in a signature. The scoring categories for this feature are:

(Score 1) Starting from the left

(Score 2) Starting from the middle

(Score 3) Starting from the right

Ending Position

The end position of the last stroke of the signature provided the following scoring system:

(Score 1) Left

(Score 2) Middle

(Score 3) Right

For each of the 188 signatures that had been replicated 10 times in 1 session and duplicated in a 2nd signing session, all the measurements and classifications of the 10 features were recorded. Examination of these data for a particular feature was used to produce frequency plots and the descriptive statistics; i.e., mean and standard deviation. The Mann-Whitney non-parametric significance test was used to ascertain if there was any significant difference in the mean values of 2 groups of data. All statistical tests were performed using SPSS for Windows software, Version 14 (2005).

Results and Discussion

A collection of signatures, including 10 replicates produced on different occasions, was obtained from 188 Arabic participants. The numbers of males and females, together with the numbers of these participants in each age group, are summarised in Table 1.

A total of 10 features were identified that were common to all signatures and included 3 that could be obtained by direct measurement, namely height (H), length (L) and height/length (H/L) ratio, and called measurable variables. The other 7 features, which could be classified according to a numerical code as described in the Materials and Methods section, were the number of strokes, number of dots, direction of ending stroke, legibility of signatures, slant, starting position, and ending position. These are called classified variables. After recording the coding assigned to all the 7 classified variables for the 1st set of 10 signatures obtained from all 188 participants, analyses were performed on each variable; and the results obtained are reported.

Legibility of Signature

Four classifications of legibility have been defined in this study, namely, legible, illegible, short form, or part legible; and the descriptive statistics, i.e., mean, standard deviation (SD) and frequency

SIGNATURES	LEGIBILITY OF SIGNATURES	FREQUENCY	%OF GROUP	MEAN	SD
All Participants (188)	Illegible Short Form Part Legible Legible	40 11 110 27	21.3 5.8 58.5 14.3	2.66	0.97
Male (128)	Illegible Short Form Part Legible Legible	32 7 73 16	23.0 5.5 57.0 12.5	2.57	1.00
Female (60)	Illegible Short Form Part Legible Legible	8 4 37 11	13.3 6.7 61.7 18.3	2.85	0.88

Table 2. Analysis of the frequency of the number and percentage of all signatures obtained in this 1st study based upon legibility.

data, are shown in Table 2. The frequency and percentage of frequency of occurrence are shown graphically in Figure 2.

It was interesting to note that about only 5% used the short form of signature, whereas over half of the participants (58%) produced a partially legible type of signature; and overall only ca. 15% produced a legible signature. The partially legible signatures contained only a very small proportion of the signature—usually only the first 1 or 2 characters—and then often only part of these characters that could be recognised as Arabic script. Hence, a high percentage of signatures did not contain many of the usual Arabic characters that occur in handwriting. Therefore, this finding provided evidence to support the proposal for the examination of a signature as a picture if trying to establish an objective approach.

It appeared that females tended to produce a more legible form of signature than males, and this may be due to females taking more time or care in writing their signatures. To see if there was any significant difference between the groups of male and female signatures, a Mann-Whitney

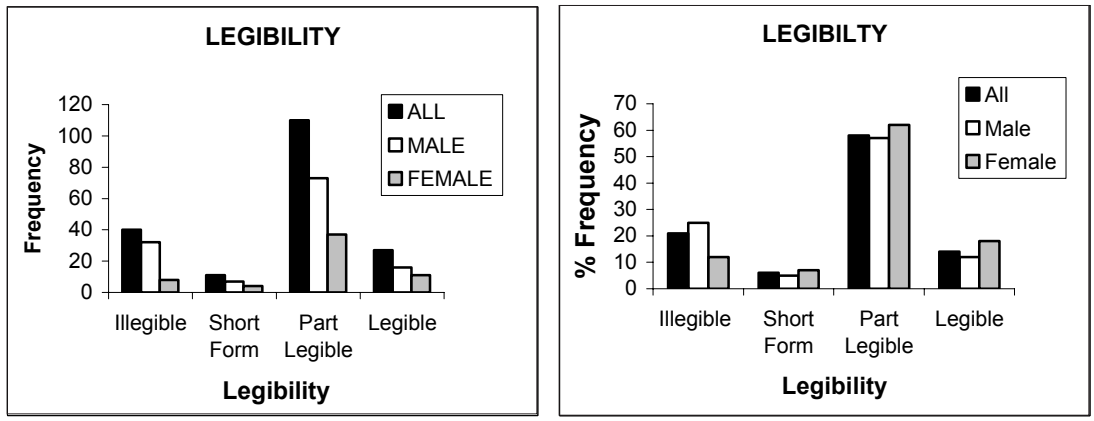

Figure 2. Graphical presentations of the frequency and pecent frequency of the legible types of the signatures recorded for all participants, males and females.

SIGNATURES	NUMBER OF STROKES	FREQUENCY	% of GROUP	MEAN	SD
All Participants (188)	1	72	38.3	2.59	1.76
	2	33	17.6		
	3	37	19.7		
	4	23	12.2		
	5	6	3.2		
	6	9	4.8		
	7	7	3.7		
	8	2	1.1		
Male (128)	1	51	39.8	2.31	1.46
	2	26	20.3		
	3	28	21.9		
	4	14	10.9		
	5	5	3.9		
	6	1	0.8		
	7	2	1.6		
	8	1	0.8		
Female (60)	1	21	35.0	3.28	2.17
	2	6	10.0		
	3	9	15.0		
	4	9	15.0		
	5	1	1.7		
	6	8	13.3		
	7	5	8.3		
	8	1	1.7		

Table 3. Analysis of the frequency of the number and percentage of all signatures obtained in this 1st study based upon the number of strokes.

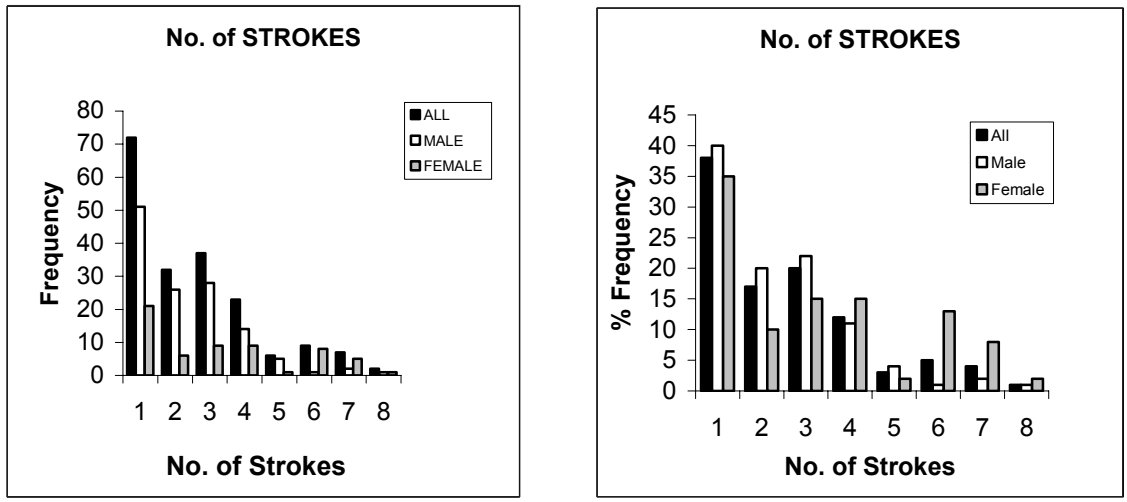

Figure 3. Graphical presentations of the frequency and percent frequency of the number of strokes in the signatures recorded for all participants, males and females

test was performed, and this produced a Z value of -1.762 and a P value of 0.78. Since the Z value was less than 1.96 (irrespective of negative sign) and the P value exceeded 0.05 (Daniel 1990) , these results showed that the legibility of a signature is not a suitable feature for discriminating between male and female groups of people.

Number of Strokes

The descriptive statistics and frequency data for the number of strokes recorded in this set of signatures are shown in Table 3. The frequency and percerntage of frequency of occurrence are shown graphically in Figure 3.

An initial observation was that no signature contained more than 8 strokes. A larger collection of signatures may possibly contain some signatures with more strokes; but on the basis of this study, a signature containing more than 8 strokes could be considered to be quite unique. These results also showed that the majority of males and females (ca 35%) completed their signature in 1 stroke, i.e., only lifted the pen off the paper at the end of writing their signatures. These data also showed that as the number of strokes counted increased up to 5, there was a decrease in the number of signatures produced by both males and females. Interestingly, the number of signatures containing between 5 and 8 strokes appeared to increase and then fall across this range. This occured with both males and females, but the results indicated that more females produced signatures with a higher number of strokes than males.

These observations are more clearly identified in the frequency plot (Figure 3) and clearly indicated that the distribution of the data was not normal; and there was evidence of a bimodal distribution. It should be noted that not all Arabic countries adopt exactly the same style of characters. For instance, in Tunisia, Algeria, and Morocco people write the "faa" (ف) with 1 dot below, and the "qaaf" (ق) with 1 dot above. They also write the "kaaf" (ك) in a joined form when most other Arab countries do not follow this practice. Hence, the 2nd higher distribution of the number of strokes in the bimodal distribution may be related to nationality or other factors such as age, education, or legibility of the participants. The personal data recorded for the individuals producing more than 5 strokes were therefore studied, and it was observed that all the participants either produced legible or part legible signatures; i.e., they tended in some degree to use more traditional Arabic characters in their signatures.

Further examination revealed that 6 out of the 9 participants using 6 strokes were from the United Arab Emirates (UAE), as were 6 of out of the 7 participants who produced signatures with 7 strokes. However, a large number of participants (42%) were of UAE nationality, and further studies involving more people from other Arabic states are required to determine if nationality has any influence over the number of strokes used in signatures.

Finally, in studying the personal details, it was noticeable that 6 of the 8 females who signed with 6 strokes and 5 females and 2 males who signed with 7 strokes were in the age range of 20 to 30. This could be related to people at this age still developing their signatures and retaining traditional writing characteristics. Again, to determine if the numbers of strokes in a signature are related to age, a much larger collection of signatures from people of different age groups would need to be studied.

To establish if the number of strokes can be used to discriminate between male and female groups, a Mann-Whitney statistical test was performed. This gave a Z value of -2.331 and a P value of 0.020; thus it was possible to discriminate between the 2 groups. These results suggested that females produce more strokes in their signatures than males. There was a reasonable explanation, as females in this collection of signatures tended to produce more legible signatures than males and/or they were more careful in signing a document than males. It should be noted that with a legible type of signature, and if following traditional handwriting, the number of strokes should be dependent on the actual name of the person and the number of characters in the signature. However, as many of the participants produced an illegible type of signature, the number of strokes used will be characteristic of the individual.

Number of Dots

In Western script, there are only 2 dotted characters (i and j), whereas in Arabic script dotted characters are used much more extensively and play a major role in the pronunciation of the Arabic language. In studying Arabic signatures, the examiner must analyse the dotting process including the writer's commitment to dotting letters, the position of the dots relative to other features and, as identified earlier, the writing style of the 2- and the 3-dots systems used. Clearly, variation in this feature may possibly provide good discrimination between signatures.

SIGNATURES	NUMBER OF DOTS	FREQUENCY	% OF GROUP	MEAN	SD
All Participants (188)	0	89	47.3	0.89	1.39
	1	63	33.5		
	2	16	8.5		
	3	10	5.3		
	4	6	3.2		
	5	2	1.1		
	6	0	0		
	7	1	0.5		
	8-12	1	0.5		
Male (128)	0	68	53.1	0.71	1.53
	1	40	31.2		
	2	11	8.6		
	3	3	2.3		
	4	5	3.9		
	5	1	0.78		
	6- 12	0	0		
Female (60)	0	21	35.0	1.26	1.92
	1	23	38.3		
	2	5	8.3		
	3	7	11.7		
	4	1	1.7		
	5	1	1.7		
	6	0	0		
	7	1	1.7		
	7-12	1	1.7		

Table 4. Analysis of the frequency of the number and percentage of all signatures obtained in this 1st study based upon the number of dots.

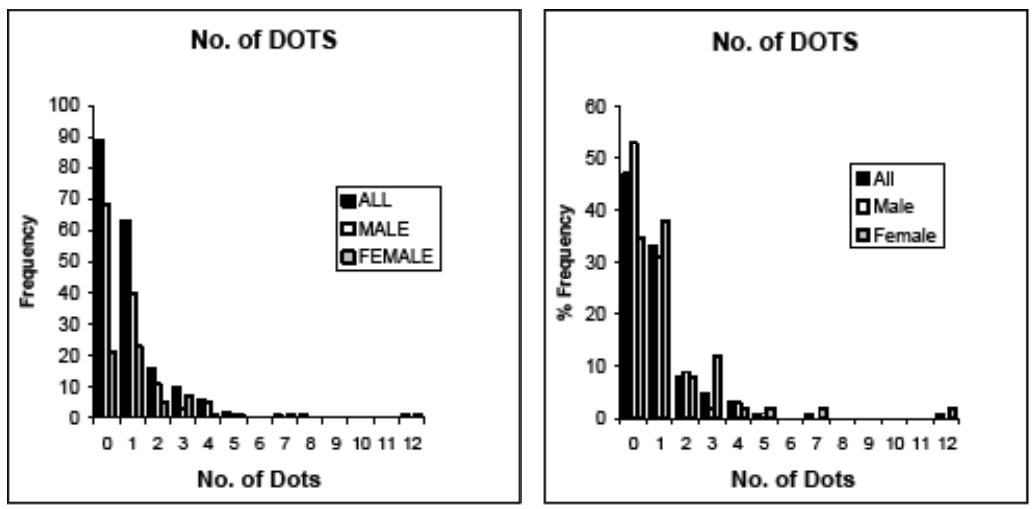

Figure 4. Graphical presentations of the frequency and % frequency of the number of dots in the signatures recorded for all participants, males and females

SIGNATURES	SLANT OF SIGNATURE	FREQUENCY	% OF GROUP	MEAN	SD
All Participants (188)	1. Left slant	39	20.7	2.14	0.73
	2. Upright slant	83	44.1		
	3. Right slant	66	35.1		
Male (128)	1. Left slant	25	19.5	2.18	0.74
	2. Upright slant	55	43.0		
	3. Right slant	48	37.5		
Female (60)	1. Left slant	14	23.3	2.1	0.73
	2. Upright slant	28	46.7		
	3. Right slant	18	30.0		

Table 5. Analysis of the frequency of the number and percentage of all signatures obtained in this 1st study based upon the slant of the signatures.

The descriptive statistics and frequency data for the number of strokes in the set of signatures recorded in this study are shown in Table 4. The frequency and percentage of frequency of occurrence are shown graphically in Figure 4.

The number of dots ranged from 0 to 12, with 47% of the signatures containing no dots. With an increasing number of dots, it was noticeable that the numbers of signatures decreased; and, interestingly, none of the 188 signatures was found to contain 6 dots. In Arabic script there are characters that when combined in signatures can give 6 dots, and so this finding was unique and provided a very useful statistic for the document examiner. It also appeared that there was no male signature that contained more than 5 dots; whereas, 2 female signatures had more than 6 dots, i.e., 1 with 7 dots and 1 with 12 dots. To confirm these findings, a study involving a larger number of participants would be necessary.

Further examination of the data shows that 53% of male signatures did not have any dots in comparison to 35% of the female signatures; and, overall, men produced signatures with fewer dots than females. One possible explanation for this is that it is generally perceived that females tend to take more time, care, and attention to detail than males; and this may be reflected in

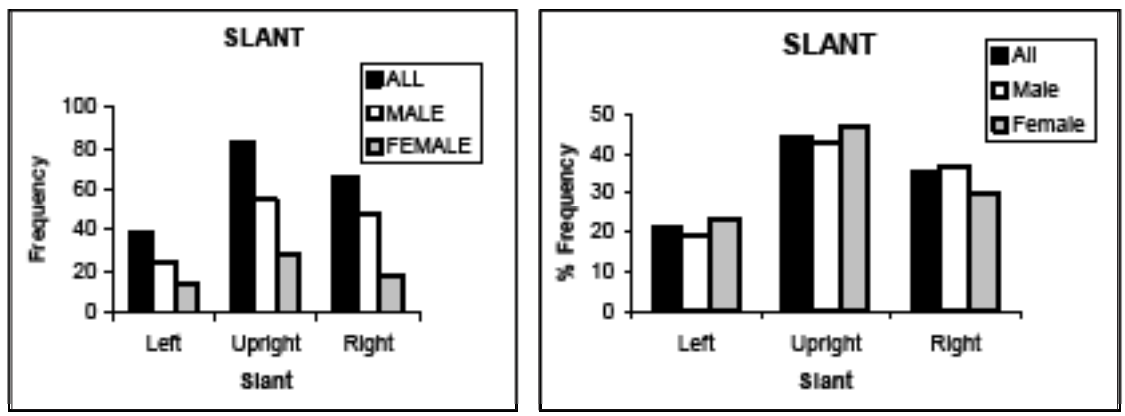

Figure 5. Graphical presentations of the frequency and % frequency of the slant of the signatures recorded for all participants, males and females.

SIGNATURES	ENDING STROKE DIRECTION	FREQUENCY	% OF GROUP	MEAN	SD
All Participants (188)	(1) Downward	108	57.2	1.60	0.72
	(2) Horizontal	62	33.0		
	(3) Upward	26	13.8		
Male (128)	(1) Downward	69	53.9	1.62	0.74
	(2) Horizontal	39	30.5		
	(3) Upward	20	15.6		
Female (60)	(1) Downward	31	51.7	1.58	0.67
	(2) Horizontal	23	38.3		
	(3) Upward	6	10.0		

Table 6. Analysis of the frequency of the number and percentage of all signatures obtained in this 1st study based upon the direction of the end stroke of the signatures.

signing documents. Hence, this is a feature that may be considered to distinguish between male and female groups of signatures; and statistical analyses were performed to test the significance of these results. This was confirmed with a Mann-Whitney test, since this produced a Z value of -2.309 and a P value of 0.21, indicating a significant difference between the mean number of dots recorded for the male and female groups.

The variation in the number of dots observed between individuals' signatures will be related to the number of dotted characters used to form the name and also to the legibility of the signature. In a legible signature, which uses traditional handwriting characters, people would be expected to include all the dots; whereas in the illegible types of signatures, people may exclude some or all of the dots. As indicated previously, more females tended to produce the legible types of signatures, i.e., follow more traditional handwriting; and this could account for female signatures possibly containing more dots than male signatures.

Slant of Signature

The 3 classifications used for the slant of a signature are left, upright, and right; and their frequency of occurrence in this set of signatures is reported in Table 5 and shown graphically in Figure 5.

Western script is written from left to right, and a right slant or upright form of writing are the more natural forms seen. It is usually accepted that only

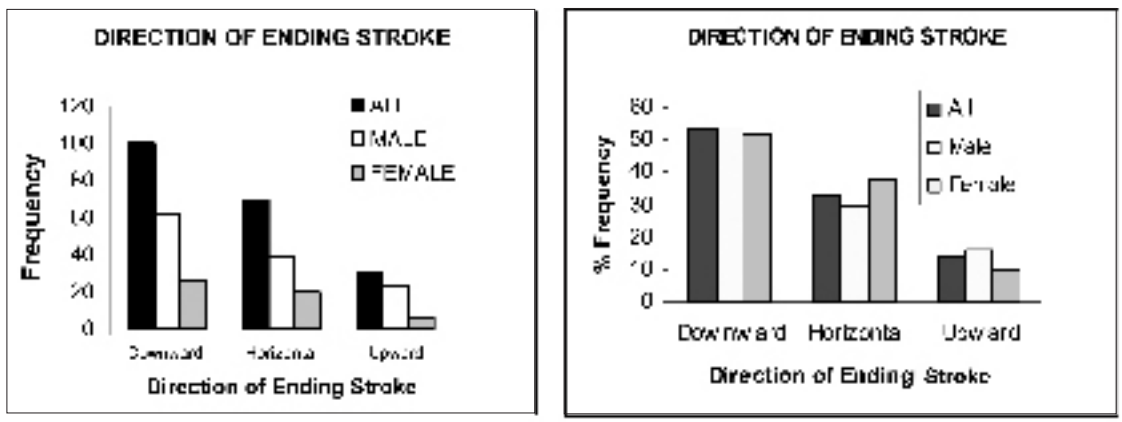

Figure 6. Graphical presentations of the frequency and % frequency of the direction of the end stroke of the signatures recorded for all participants, males and females.

SIGNATURES	STARTING POSITION	FREQUENCY	% OF GROUP	MEAN	SD
All Participants (188)	1. Left	31	16.5	2.29	0.73
	2. Middle	71	37.8		
	3. Right	86	45.7		
Male (128)	1. Left	20	15.6	2.28	0.72
	2. Middle	53	40.6		
	3. Right	56	43.7		
Female (60)	1. Left	11	18.3	2.33	0.77
	2. Middle	19	31.7		
	3. Right	30	50.0		

Table 7. Analysis of the frequency of the number and percentage of all signatures obtained in this1st study based upon the starting position of the signatures.

about 20% of Western scripts slant to the left; and many left-handed writers, but not exclusively, tend to produce script with this direction of slant. Arabic script, however, is produced in the opposite direction; and therefore, as acknowledged by Arabic forensic document examiners, it might be expected that the predominant slant would be upright or in the direction of the writing, i.e., to the left. However, these results showed that this was not the case, with only about 20% producing left-slanted signatures and the majority following the Western script pattern of producing either right-sloping or upright signatures. Since only about 15% of the signatures in the collection could be classified as legible and therefore typical of handwriting (i.e., left slanted), this was consistent with the number of left-slanted signatures observed in this collection of signatures.

The percentage of frequency data presented in Figure 5 indicated that there was no significant difference between the slant of the male and female groups; and this was confirmed with a Mann-Whitney test, with Z and P values of -1.000 and 0.371 being recorded. However, studying the slant of signatures provides a method for assessing variation between individuals, as this is another feature which is not name-dependent and therefore characteristic of the individual.

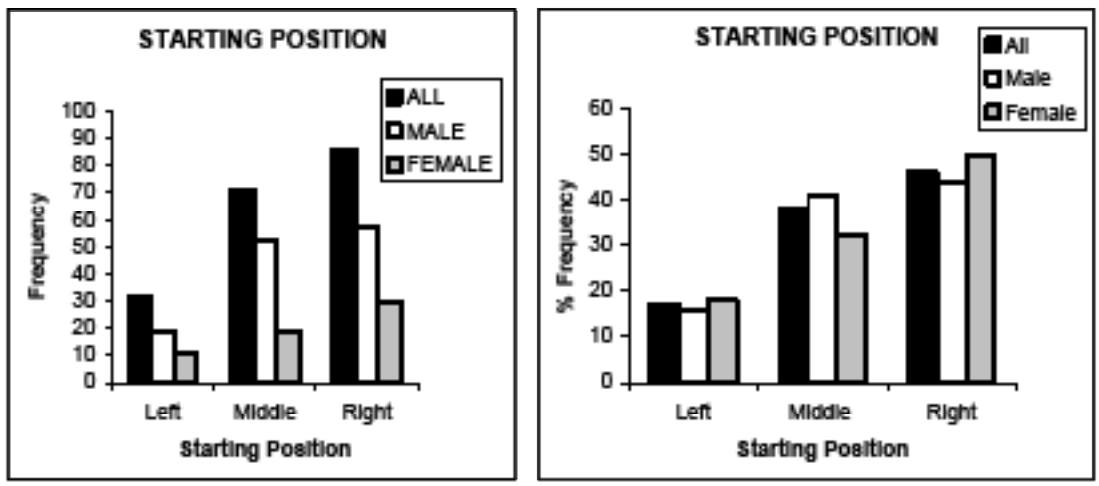

Figure 7. Graphical presentations of the frequency and % frequency of the starting position of the signatures recorded for all participants, males and females.

SIGNATURES	ENDING POSITION	FREQUENCY	% OF GROUP	MEAN	SD
All Participants (185)	1. Left	91	48.40	1.66	0.72
	2. Middle	69	36.7		
	3. Right	28	14.9		
Male (135)	1. Left	63	49.2	1.70	0.77
	2. Middle	41	32.0		
	3. Right	24	18.7		
Female (60)	1. Left	28	46.7	1.60	0.62
	2. Middle	28	46.7		
	3. Right	4	6.7		

Table 8. Analysis of the frequency of the number and percentage of all signatures obtained in this 1st study based upon the ending position of the signatures.

Direction of End Stroke

The direction of the end strokes in the signatures, together with their frequency of occurrence in this set of signatures, are reported in Table 6 and shown graphically in Figure 6.

These results confirmed that about 50% of all males and females completed their signature with a downward stroke, and the trend then is that fewer males (30%) and females (38%) sign with a horizontal stroke and even fewer males (16%) and females (10%) complete their signatures with an upward stroke. With a Z value of -0.086 and a P value of 0.931 being obtained with a Mann-Whitney test, this confirmed that there was no significant difference between the male and female groups.

If all signatures were of the legible type, the character at the end of the signature would be expected to dictate the direction of end stroke. However, since about 85% of the signatures in this collection were of the illegible type, the ending stroke direction was a characteristic of the individual.

Starting Position

The 3 classifications used for the starting position of a signature were left, middle, and right; and their frequency of occurrence in this set

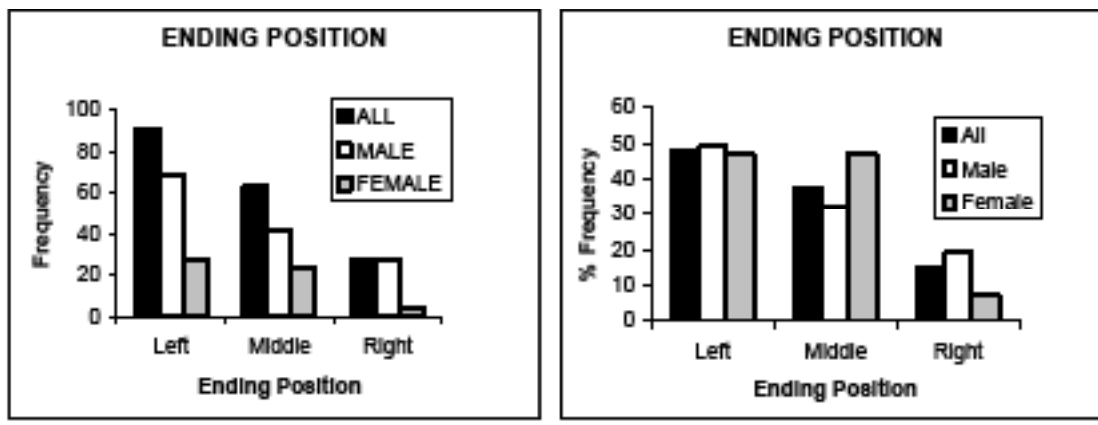

Figure 8. Graphical presentations of the frequency and % frequency of the ending position of the signatures recorded for all participants, males and females.

of signatures is reported in Table 7 and shown graphically in Figure 7.

With Arabic writing starting on the right and moving left, the expectation is that the majority of participants would possibly start their signatures at the right. The results, however, showed that this was not the case; and only 46% of all the participants started their signatures at the right, with 38% starting in the middle and about 16% starting from the left. Hence, with many of the participants not following conventional handwriting practice, this study again supported the opinion that signatures are a specialised form of handwriting.

A Mann-Whitney test was performed to establish if gender had any influence on the starting position of signatures. A Z value of -0.450 and a P value of 0.653, confirmed that there was no significant difference between the male and female groups of participants. However, this feature is a characteristic of an individual and, therefore, one that can be used to study variation between signatures.

Ending Position

As with the starting position, 3 classifications were used for the ending position of a signature, namely, left, middle, and right; and their frequency of occurrence in this set of signatures are reported in Table 8 and shown graphically in Figure 8.

Based on the results of the starting position of signatures and whether the participants followed traditional handwriting practice, it may be expected that a similar number of the participants would end their signatures in the left position. The results confirmed this, with 48% of the participants completing their signatures in the left position. It is also interesting to note that a comparison of the graphical data in Figures 7 and 8 shows that the ending position results are virtually a mirror image of the starting position results, with 37% ending in the middle of their signature and 15% ending in the right position.

Since signatures in this study have been shown not to follow conventional handwriting practice, it must not be assumed that if a signature starts on the right it will end on the left, as the above data may indicate. This is because people could start their signatures on the right but then end in the middle. Hence by studying a combination of both starting and ending positions and both being characteristics of an individual, these details may provide forensic document examiners with further information about the variation between signatures and assist in the examination of signatures.

A Mann-Whitney test was performed to establish if gender had any influence on the ending position of signatures. A Z value of -0.491 and a P value of 0.623 confirmed that there was no significant difference between the male and female groups of signatures.

Moving onto the 3 measurable variables, which included the height, length, and H/L ratio, the measurements for these features for the 1st set of the signatures from all 188 participants were recorded. These data were then analysed in a similar manner to the classified variables, and the results are presented and discussed.

Variation in Height

The descriptive statistics obtained from measuring the height of all signatures in this study are presented in Table 9, and histograms showing the frequency of occurrence plots are shown in Figure 9.

From these results it can be observed that males produced signatures of greater mean height, e.g., 17 mm compared with 12 mm, and with a wider range of heights than females, e.g., 31 mm compared with 21 mm. These results also confirmed that both groups showed similar and high degrees of natural variation in height of the signatures with an Relative Standard Deviation (RSD) of about 40%. However, A Mann-Whitney test confirmed that with a Z value of -5.052 and a P value of 0.000, it was possible to use this feature to distinguish between the group of males and females within this collection of signatures.

In normal handwriting, the height of a word depends on the characters present, and comparisons between writers can be made by measuring the heights of the characters. However, the signatures in this collection were shown to be predominantly of the illegible type and therefore did not have the usual Arabic characters. Hence, this method of using characters for comparisons between signatures, even for people whose names share the same characters, cannot be performed. The height of a signature, however, can still be used if a signature is viewed as a picture, as it is not name dependent and characteristic of the individual.

Variation in Length

The descriptive statistics obtained from measuring the length of all signatures in this study are

GROUP ( ) No in Group	HEIGHT OF SIGNATURE (mm)				
	MINIMUM	MAXIMUM	MEAN	RANGE	STANDARD DEVIATION
All Participants (138)	3.96	34.89	15.38	31.13	6.30
Male (118)	3.96	34.89	16.81	31.13	6.33
Female (60)	5.17	25.55	12.04	20.38	4.93

Table 9. Descriptive statistics for the height measurements of all signatures examined in this 1st study.

presented in Table 10, and histograms showing the frequency of occurrence plots are shown in Figure 10.

Results very similar to those regarding the height of signatures were obtained when studying the length of signatures. The males produced signatures of greater mean length than females, e.g., 39 mm compared with 34 mm, and with a wider range of lengths than females, e.g., 71 mm compared with 54 mm. These results confirmed that both groups also showed similar high degrees of variation in the length of the signatures, with an RSD of about 40%. A Mann-Whitney test confirmed that it was possible to use this feature to distinguish between the male and female groups within this collection of signatures, as a Z value -2.461 and a P value of 0.014 were obtained.

In normal handwriting, the length of a word depends on the number and width of characters used, and comparisons between writers can be made by measurement of the widths of the individual characters. Again, as with the height of a word, direct comparisons between the length of signatures, even for people whose name shared the same characters, could not be performed, as the signatures in this collection were predominantly of the illegible type. However, if viewing a signature as a picture, then the length could be characteristic of an individual's signature and therefore provide a useful feature for studying variation between individuals in a collection of signatures.

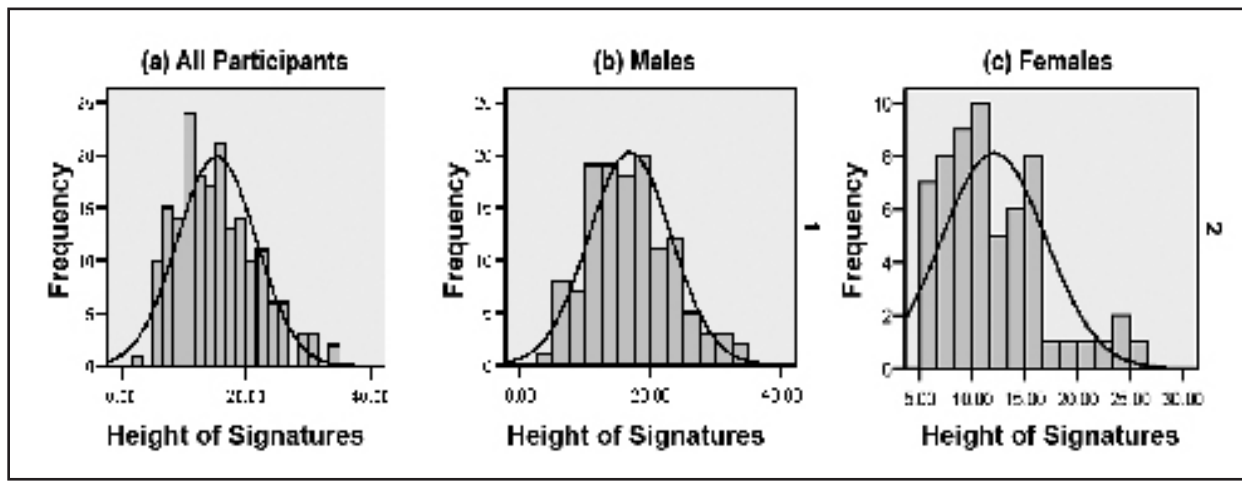

Figure 9. Histograms showing the frequency of occurrence of height measurements in this set of signatures for (a) all participants, (b) males and (c) females.

GROUP ( ) No in Group	LENGTH OF SIGNATURE (mm)				
	MINIMUM	MAXIMUM	MEAN	RANGE	STANDARD DEVIATION
All Participants (188)	8.58	78.67	37.59	70.59	14.40
Male (128)	8.58	78.67	39.31	70.59	14.69
Female (60)	15.65	70.15	33.92	54.50	13.12

Table 10. Descriptive statistics for the length measurements of all signatures examined in this 1st study.

Variation in Height/Length Ratio

The descriptive statistics obtained from measuring the H/L ratio of all signatures in this study are presented in Table 11, and histograms showing the frequency of occurrence plots are shown in Figure 11.

Again, as observed with the height and length of signatures, very similar results were obtained when studying the H/L ratios. The males produced signatures of greater mean H/L ratios than females, e.g., 0.48 compared with 0.38., and with a wider range ratios than females, e.g., 2.32 compared with 0.99.

With the high degrees of variation found within both the length and height of the male and female groups of signatures, it was expected that, unless there was a high level of dependency between these 2 features, i.e., an increase in length leads to an increase in height, a wide variation in the ratios would be observed. This was confirmed from these results, but the variation within the male group was greater (58% RSD) than in the female group (42% RSD). This difference could again be due to greater care taken by females or because this group tended to produce more legible signatures than males.

From the histograms it can be observed that in both the male and female groups some ratios are outside of the frequency of distribution range of the H/L ratio values. These were determined not to be outliers, as shown in the case of the male group where the H/L ratio of 2.4-2.5 was found to

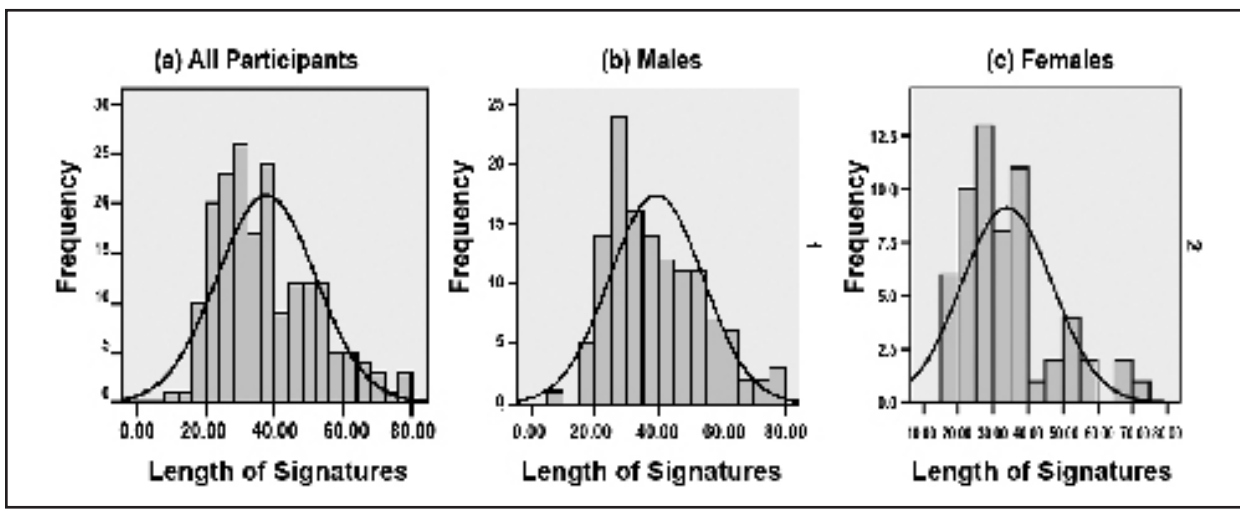

Figure 10. Histograms showing the frequency of occurrence of length measurements in this set of signatures for (a) all participants, (b) males and (c) females.

GROUP ( ) No in Group	HEIGHT/LENGTH RATIO OF SIGNATURE				
	MINIMUM	MAXIMUM	MEAN	RANGE	STANDARD DEVIATION
All Participants (188)	0.13	2.44	0.45	2.32	0.25
Male (128)	0.13	2.44	0.48	2.32	0.28
Female (60)	0.15	1.14	0.38	0.99	0.16

Table 11. Descriptive statistics for the H/L ratios of all signatures examined in this 1st study.

originate from 1 person who produced 10 signatures consistently with this H/L ratio. Similarly, the ratio of 1.1-1.2 observed in the female group was shown to be produced by 1 female who again produced 10 signatures consistently with this H/L ratio. These results indicated that in this collection of signatures, these particular people had relatively unique and consistent signatures, thus confirming that the H/L ratio can be a useful feature for studying variations between individuals.

A Mann-Whitney test confirmed that, based upon H/L ratio vales, it was possible to use this feature to distinguish between the male and female groups within this collection of signatures, as a Z value -2.643 and a P value of 0.008 were obtained.

Duplicated Trial Results

As indicated earlier, the above study was duplicated by examination of a 2nd set of signatures. This set of signatures was produced in another session by all participants who were requested to provide another set of 10 signatures. The purpose of this 2nd trial was to establish consistency of the selected variables. For the sake of brevity, the full results have not been presented but are summarised here. With the classified features, the descriptive statistics for the number of dots, slant, and starting position, were identical to those recorded in the 1st study, thus indicating an excellent level of consistency between the 2 sets of signatures for these particular features. Some minor differences were observed for the other 4

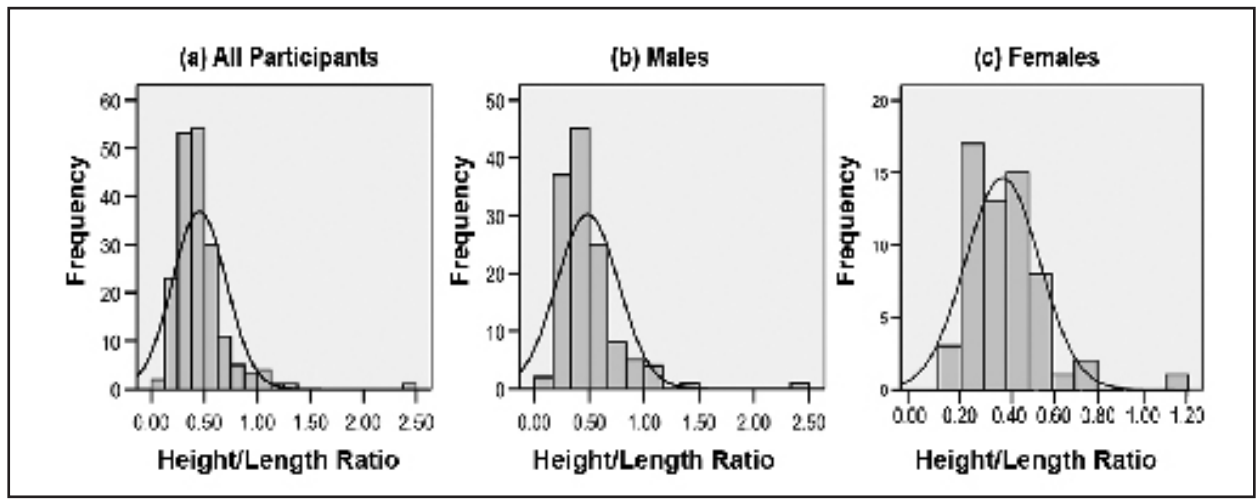

Figure 11. Histograms showing the frequency of occurrence of H/L ratios in this set of signatures for (a) all participants, (b) males and (c) females

FEATURE	MANN-WHITNEY			
	Z VALUE		P VALUE	
	A	B	A	B
Legibility	-1.782	-1.561	0.078	0.119
No. Strokes	-2.331	-2.567	0.020	0.010
No Dots	-2.309	-2.308	0.021	0.021
Short	-1.000	-1.000	0.317	0.317
Ending Direction	-0.086	-0.371	0.931	0.711
Starting Position	-0.45	-0.733	0.653	0.464
Ending Position	-0.491	-0.530	0.623	0.596
Height	-5.052	-4.217	0.000	0.000
Length	-2.461	-2.443	0.014	0.015
H/L Ratio	-2.643	-1.378	0.008	0.168

Table 12. A comparison of the Mann-Whitney test results for the 2 sets of signatures (Initial Study and Replicated Study). Features considered the most suitable for trying to determine if there are any significant differences between the male and female groups are highlighted.

features, and these can be attributed to natural variation which can be influenced by such factors as speed, number of replications required, writing conditions, and complexity of the signature.

When examining each of these 4 features, complexity of the signature and speed were identified as being the most influential factors. As a signature becomes more complex, this can lead to greater variations, firstly because the writer may have more difficulty in reproducing and secondly, as experienced in this study, more difficulty in observing features such as the number of strokes. This emphasises the need for careful and detailed examination when studying and comparing complex signatures. The effects of speed of signing were also apparent when, for example, trying to classify the legibility and ending strokes of a signature. With the latter, a 7% change, the highest level of variation observed in this study for any of the classified features, was observed, with fewer participants finishing with a downward stroke than in the 1st study.

With the 1st of the measurable variables, it was found that the height of the signatures from all the participants resulted in slightly larger maximum and minimum values (ca. 3 mm) in the second trial; but these produced only minimal changes in the mean, range, and standard deviation values. However, when examining results from the male and female groups, it was observed that the minimum height of the males' signatures had increased by about 2 mm, with no major changes in the mean, range, or standard deviation values. The maximum height of the females' signatures increased from 25.55 to 36.90 mm; and this produced some increase in the mean, range and standard deviation values. These results indicated that between the 2 sets of signatures, the male group tended to exhibit slightly better consistency in the height of their signatures than the female group and overall illustrated the relatively low degree of natural variation that was observed between individuals when signing on different occasions.

When comparing the length of the signatures between the 2 trials, changes in the descriptive statistics were found to be very similar to those observed for the height measurements. The male group again produced a slightly higher level of consistency than the female group. These results confirm that overall there is a high level of consistency in the length of the signatures which were produced on 2 separate occasions.

The H/L ratio data from the 2 trials gave very similar descriptive statistical results, and it was

still possible to identify the same male and female who had provided signatures with higher H/L ratios than the rest of their group. This illustrated a high level of reproducibility between the duplicate sets of the data of these 2 people. However, overall this was not found to be the situation, since the percentage RSD values showed that the variation of the ratio had increased slightly in the 2nd trial for both the male (61% vs 58%) and female (46% vs 42%) groups.

In the 1st trial it was found, through the use of the Mann-Whitney, that significant differences were observed between the male and female groups for the some of the features. The test was also used of data obtained in this 2nd study, and a comparison of the result between the 2 set of signatures is shown in Table 12.

These results show that in the 2nd study 4 of the 5 features, namely, number of strokes, number of dots, height, and length, still show significant differences between the male and female groups, thus showing the consistency of these features of the signatures obtained for the 2 studies. The results from the Mann-Whitney test do show, however, that whilst discrimination between the male and female groups could be achieved with the H/L ratio for the 1st set of signatures, no significant difference can be observed between the 2 groups in the 2nd study. This can be attributed to a combination of the higher levels of variation observed for both height and length measurements of the signatures of the male and female groups and the slightly higher degree of variation in the 2nd set of signatures.

Conclusions

The collection of signatures and replicates from signatures produced on different occasions by 188 participants has provided a unique reference library of Arabic signatures. With 85% of these signatures found to be illegible, the proposal to use 10 features common to all of these signatures has provided a unique approach for studying the variation in Arabic signatures. The 10 features (variables) selected included 3 measurable variables (height, length, and H/L ratio) and 7 classified variables (number of strokes, number of dots, direction of ending stroke, legibility of signatures, slant, starting position, and ending position).

Descriptive statistical data and frequency plots from 1 study involving all participants who produced 10 replicates of their signature on 1 occasion established that all features provide the forensic document examiner with valuable reference data. When trying to analyse these data, legibility was shown to have a considerable influence on features such as slant and ending and starting positions. With 2 of these features, (number of dots and number of strokes) and the H/L ratio plots, it was possible from their frequency distribution data to identify that some signatures were unique. It was also possible from studying the slant of signatures to identify that more participants produced right- as opposed to the normally expected left-slanted signatures; and a larger number of females were identified as using more strokes than males. There was also an indication that the number of strokes used may be related to the age of the females or other factors such as legibility, country of origin, or educational background. However, to confirm this hypothesis, a larger set of signatures would need to be studied.

Data gathered for each feature were subjected to a Mann-Whitney statistical test. With 5 of the features (number of strokes, number of dots, height, length, and H/L ratio) it was possible to show that there was a significant difference between signatures produced by the male and female groups of participants.

A 2nd set of 10 replicated signatures produced by all the participants on another occasion was used to evaluate the consistency of any variation observed for each of the selected features. The largest variation (7%) was obtained with the number of strokes and highlighted the care required in the examination of complex signatures. With the Mann-Whitney results, significant differences between the male and female groups were still achieved with 4 of the 5 features. No significant difference between the 2 groups could be obtained with the H/L ratio in this 2nd study due to the high level of variation in both the height and length of the males and females in each study and the slightly higher precentage RSD levels for the males (61% versus 58%) and the females (46% versus 42%) recorded in the 2nd study. However, from the descriptive statistics obtained in this 2nd study, it was still possible to show, by using the H/L ratios, that 1 male and 1 female participant within each of their groups appeared to produce a unique signature. A larger set of signatures would help confirm this finding; and more signatures could improve the level of knowledge already gained in this initial study regarding variation in Arabic signatures. In a continuation of this study, which is to be published, these data have been

examined to provide quantitative analysis on the natural variation within an individual's signature and the variation in signatures when produced on different occasions.

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