A STATISTICAL ANALYSIS FOR INDENTIFICATION OF KOREAN HANDWRITING

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A STATISTICAL ANALYSIS

FOR

IDENTIFICATION OF KOREAN HANDWRITING

By

Sung Tai Cho

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The research reported in this paper was an exploratory study of the possibility of using inferential statistical methods in handwriting analysis. Two inherent characteristics of handwriting--internal variation of a single individual and coexistence of dissimilarities with similarities in writings made by more than two different individuals--make handwriting identification problematic.

Current methods of identification do not completely solve the problems presented by these factors, because, while they do consider similarity and difference, they do not provide objective criteria for deciding how much similarity there must be before it can be concluded that samples of writing were made by the same person or how much dissimilarity there must be before it can be concluded that samples were made by different persons. Technique of inferential statistics was developed in order to deal with the same type of problem in other areas of inquiry and an examination of the conceptual and mathematical structure of this technique suggests that it can be legitimately used in the area of handwriting analysis.

The present study was limited in scope in several ways. The study was based on the measurement of elements of a single character. The measuring instrument developed by the writer for the study was restricted to line and angular measurement and was not capable of measuring stroke curvature. Small samples were used. In spite of these limitations the statistical tests used led to correct identification in 69 percent of the cases for the least discriminating

element and in 86 percent of the cases for the most discriminating element. Furthermore, it has been shown that the accuracy of identification based on a single element can be improved by increases in sample size and by changing the region of rejection of the null hypothesis. This, to emphasize, is possible. The findings, then seem to demonstrate that the techniques of statistical inference hold great promise for improvements in handwriting identification.

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CHAPTER I

INTRODUCTION

1. The Problem

At present handwriting identification, unlike fingerprint identification, has not yet reached a level of validity and reliability which will permit its full acceptance either by criminological science or by the courts of law. The difficulty of developing a scientifically valid and legally acceptable handwriting identification lies in the nature of handwriting itself. In terms of consistency and individual uniqueness handwriting occupies the opposite end of a continuum from fingerprints. Repeated prints made by a given finger of a particular individual are both consistent, in that they exhibit no important variation, and unique, in that they are demonstrably different from prints made by any other individual.

Handwriting, on the other hand, is both internally variable and not completely unique. Within the writings of a given person there will be variation in the way that the same letter is formed, while the writings of two individuals will generally show some dissimilarities as well as similarities. Present methods of handwriting identifica-

tion are not entirely satisfactory because they do not solve the problems posed by internal variation and by the coexistence of similarity and dissimilarity in questioned and standard writings.[1]

The present study was an attempt to develop a method of handwriting identification based on statistical analysis which it is hoped will constitute an advance in the precision of present identification methods. It is also hoped that this technique will meet the scientific criteria of objectivity, reliability and validity since any criminal identification method must meet these criteria before it will be accpeted by courts of law.

The remaining part of the present chapter will be concerned with a review of present handwriting methods and with an outline of the method developed in the present study.

2. The Nature of Handwriting

As the preceeding discussion pointed out, handwriting has, for identification purposes, two salient characteristics: internal variation and a lack of individual uniqueness which leads to the

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[1] "Questioned writing" is a handwriting specimen whose authorship is disputed or unknown. Osborn uses the term "questioned writing" in referring to documents in general while Hilton uses the word both in this sense and in the sense of disputed writing. "Standard writing" or "sample writing" refers to a handwriting specimen which may be taken from documents known to be written by the suspect or which may be requested from the suspect. See Ordway Hilton, Scientific Examination of Documents, Chicago: Callaghan and Company, 1956, pp. 10-11, 141-142; Wilson R. Harrison, Suspect Documents: Their Scientific Examination, New York: Frederick A. Praeger Inc., 1958, pp. 292, 297-307; Albert S. Osborn and Albert D. Osborn, Questioned Document Problems: The Discovery and Proof of the Facts, Sixth Printing, Albany, N.Y.: Boyd Printing Company, 1947, pp. 14, 22, 205-206, 352.

overlapping of characteristics in writing made by two individuals.

It is generally accepted that no individual writes in a completely uniform manner--within a sample of handwriting made by a given individual there will be variations in the way that a given letter is made.[2] This variation results from variation in writing conditions,[3] writing materials and writing instruments and from the fact that there is a lack of machine-like precision on the part of the writer.[4] This last factor is particularly important since variation occurs in a given individual's writing even when writing conditions and materials are held constant.

The second characteristic of handwriting--the lack of complete uniqueness in a given individual's writing which leads to a coexistence of similarity between writings made by different individuals--

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[2]To mention only a few John J. Harris, "How much do people write alike: a study of signatures," Journal of Criminal Law, Criminology and Police Science, 48(1), Vol. 6, March-April, 1958, pp. 647-651; Wilson R. Harrison, Suspect Documents: Their Scientific Examination, New York: Frederick A. Praeger Inc., 1958; Ordway Hilton, Scientific Examination of Documents, Chicago: Callaghan and Company, 1956: Idem., "Proper Evaluation of Dissimilarities in Handwriting," International Criminal Police Review, 104, January, 1957, pp. 48-51; Albert S. Osborn and Albert D. Osborn, Questioned Document Problems: The Discovery and Proof of the Facts, Albany, N.Y.: Boyd Printing Company, 1944; Idem., The Problem of Proof, Sixth Printing, Albany, N.Y.: Boyd Printing Company, 1947.

[3]Harrison, Ibid., pp. 3, 297, 331-333, 439; Hilton, Ibid., pp. 215-218, 246, 247; Osborn, loc. cit.

[4]Harrison, Ibid., p. 298; Hilton, Ibid., p. 141; Osborn, Ibid., p. 205.

has been discussed by several writers.[5] The coexistence of similarity may result from the fact that individuals whose writings show similarity have learned a similar "style characteristic."[6] In some cases it may be merely the result of random chance.

These factors have, to the present, put rather severe limitations on handwriting identification as a technique in criminal law. In any case where specimens of writing are compared there are two possibilities: either the writings were made by the same individual or by two different individuals. The factors of variation and coexistence mean that, regardless of the element of combination of elements of the writing used in the identification process, there will usually be differences between the writings made by the same individual and similarities in writings made by different individuals. This problem of ambiguity which makes a positive decision about the authorship of a specimen of writing inherently difficult, has not

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[5] Wilson R. Harrison, Suspect Documents: Their Scientific Examination, New York: Frederick A. Praeger Inc., 1958; Ordway Hilton, Scientific Examination of Documents, Chicago: Callaghan and Company, 1956; Albert S. Osborn, and Albert D. Osborn, Questioned Document Problems, The Discovery and Proof of the Facts, Albany, N.Y.: Boyd Printing Company, 1944. However, the lack of uniqueness in handwriting does not necessarily invalidate individuality of handwriting of a given individual. See Hilton, Ibid., p. 136, 141; Osborn, Ibid., p. 231, 270. Nor does internal variation necessarily preclude identification of individuality. In fact, this is the basis of the whole identification effort.

[6] Harrison distinguished "style" and "personal" characteristics, and the first step in handwriting identification ought to be the distinction between them. See Harrison, Ibid., pp. 288-289. To borrow Harrison's distinction, identification is pursuit of "master pattern," which may be defined as "personal" characteristics.

been entirely solved by existing identification methods which depend largely on finding similarities or dissimilarities in questioned and standard writings. Osborn, who was aware of this fact, warned against identification based solely on either similarity or dissimilarity:

> (By this same method) of ignoring differences (dissimilarities) and looking only for similarities almost any two things not altogether unlike, can be proved to be the same. This is the basis of the common error of the incompetent witness in identifying the writing in anonymous letters. Similarities can always be found in two writings in the same language or in two writings not utterly unlike. Mere similarities do not necessarily prove genuiness any more than mere superficial differences necessarily prove lack of genuiness. The incompetent witness, notwithstanding this fact, by dependence upon similarities alone reaches the conclusion of genuiness, or by dependence upon differences alone reaches the conclusion of lack of genuiness. . . .[7]

It seems evident, then, that a legally and scientifically acceptable handwriting identification system must be based on a technique which can control for variation and coexistence of similarity. A review of the literature on handwriting identification, presented in the following section, indicates that current methods have not yet completely developed such a technique.

3. Current Identification Methods

Handwriting identification methods can be classified as micro-examination or the examination of writing elements--stroke lengths,

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[7] Albert S. Osborn and Albert D. Osborn, Questioned Document Problems: The Discovery and Proof of the Facts, Albany, N.Y.: Boyd Printing Company, 1944, pp. 240-241. See also Idem., pp. 237, 244.

angles between strokes, etc., and macro-examination which is a method which classifies handwriting into styles on the basis of letter design.

Current handwriting identification analysis usually combines macro-examination with a form of micro-examination called the "comparative method."[8] Better terms for "comparative method" would be the "one-to-one" method or the "juxtaposition" method since, in the final analysis, all handwriting examination is comparative.[9]

In the one-to-one method an element of the questioned writing is juxtaposed with a similar element in the suspected writing and the two elements are compared for similarity or dissimilarity. In this type of comparison the average or modal pattern of the two writings is not considered. Such a method is inadequate since it does not take into consideration the internal variation of the two writings and the likelihood of similarity between at least some elements of the questioned and suspected writing. Random selection of elements to be compared may lead to similar elements being selected from dissimilar writings or dissimilar elements being selected from similar writings.

In recent studies, Sjoegren and Smith have attempted to overcome the problems caused by variation and coexistence of similarity by the use of a system of weighting.[10] In this system of evaluation

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[8]For instance, Tore Sjoegren combined measured characteristics with general features of handwriting, such as arrangement, spacing, connections, etc. Tore Sjoegren, "Handwriting Comparison and Probability," International Criminal Police Review, Vol. 92, Nov. 1955, pp. 274-283. Stanley Smith suggested use of the latter group characteristics in the "Secondary Examination." Stanley S. Smith, "A Method of Comparing Written Documents," ibid., Aug.-Sept. 1954, pp. 205-215. Others such as Harrison, Hilton and Osborn are of the same opinion.

[9]Harrison, Hilton, Osborn used juxtaposition method for illustrations in their texts.

[10]Ibid.

each similarity in a particular element is given a plus rating and each dissimilarity is given a minus rating. These weights are summed algebraically in order to determine the overall tendency to similarity or dissimilarity.

Hilton has argued that this method is not entirely adequate and has suggested that the major emphasis in evaluation be placed on the factor of dissimilarity:[11]

> Rather it is an analysis of the true meaning of the dissimilarities and if they are found to be basic and without logical explanation, the realization that these differences are the controlling factors which establish that the known (standard) and unknown (questioned) writings are by two distinct persons.

Harrison is in general agreement with Hilton on the importance of dissimilarity.[12] Osborn, although agreeing at some points with Hilton, suggests that similarity should be given equal weight:[13]

> The process of comparison in any field is reasoning regarding similarities and differences, and necessarily the subject has an important place in all kinds of investigations. Errors in identification problems are due not only to the failure to see the outside things but to the failure to recognize their real differences and their fundamental similarities and to understand them and interpret them when they are seen. Much of what is called science is merely accurate classification resulting from intelligent observation and reasoning leading to a correct recognition of similarities and differences.

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[11] Ordway Hilton, "Proper Evaluation of Dissimilarities in Handwriting," International Criminal Police Review, No. 104, January 1957, p. 49. Hilton has kept this view consistently in other places: Ordway Hilton, Scientific Examination of Documents, Chicago: Callaghan and Company, 1956, pp. 51, 136-137, 144.

[12] Harrison, ibid., pp. 343-345.

[13] Albert S. Osborn and Albert D. Osborn, Questioned Document Problems: The Discovery and Proof of the Facts, Albany, N.Y.: Boyd Printing Company, 1944, p. 237. See also Hilton, Scientific Examination of Documents, p. 143.

Three weaknesses seem apparent in current techniques. The method of juxtaposition is obviously inadequate since it does not take into consideration the variability factor. Second, the emphasis placed by some writers on the factor of dissimilarity has no adequate theoretical ground since it stresses only one aspect of variability. Third, the weighting method developed by Sjoegren and Smith, while avoiding the first two weaknesses, can be criticized on the ground that it fails to provide a method for determining the degree of positive or negative weighting necessary to permit acceptable inference about authorship.

It seems evident that some fresh approach will be necessary in order to develop a handwriting identification method which can cope with the problems of variation and coexistence of similarity.

4. The Study

The study reported in this paper was an exploratory attempt to apply the technique of statistical inference to the problem of handwriting identification.[14] A comparison of the problems confronting the handwriting identification specialist and the problems typically encountered by biological or social scientists attempting to make inferences about samples of variable material show that in many essential respects they are remarkably similar.

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[14]The Theory and application of inferential statistics will be discussed in more detail in Chapter III. See Helen M. Walker and Joseph Lev, Statistical Inference, New York: Holt, Rinehart and Winston, 1953; W. Allen Wallis and Harry V. Roberts, Statistics: A New Approach, Glencoe: The Free Press, 1956.

Many research hypotheses in the biological and social sciences require that the investigator determine whether two samples, alike in some respects and different in others, were drawn from the same universe of measurement. The problem cannot be solved by a simple examination of the samples since differences may have occurred as a result of the sampling error inherent when samples are drawn from a heterogeneous universe of measurement. Inferential statistics allow the researcher to reject or accept the hypothesis that the samples were drawn from the same universe, not with absolute certainty, but with a specified small margin of error.

Handwriting identification can be conceptualized as a problem in sampling. The examiner has two (or more) samples of writing which will usually show both similarities and dissimilarities. These may be drawn from two different universes (i.e., made by different individuals) or they may have been drawn from the same universe (i.e., made by the same individual) and show differences because of sampling error.

In the present study specimens of Korean handwriting collected by the researcher were treated as statistical samples. Measurements of certain micro-characteristics were made and these measurements were subjected to statistical analysis in order to determine whether inferential statistical methods could differentiate between samples whose authorship was known a priori.

The present study was limited in three respects. First, only Korean writing was used in the present study because of the writer's familiarity with this writing system. Second, only a limited set of

measurements were used. No attempt was made to evaluate macro-characteristics statistically, although macro-characteristics were used in determining the final sample, and only a small set of micro-measurements were used. Finally, no attempt was made in the present study to analyze disguised writing. Although the present study was limited there are obviously rich potentialities for statistical investigations of handwriting using other languages and more refined methods.

In the following chapter there is a discussion of the Korean language and handwriting system, with particular attention to problems in identification inherent in this writing system. Chapter III discusses in detail the statistical methods, samples and measuring techniques used in the study and presents an analysis of findings.

CHAPTER II

THE KOREAN LANGUAGE AND WRITING SYSTEM[1]

Because the technique of handwriting identification reported in this paper was based on samples of Korean writing a brief discussion of the Korean language and writing system is appropriate.

The History and Classification of the Korean Language

Most linguists classify Korean in the Altaic language group which in turn is considered to be closely related to the Ural group. If there is such a relationship, then Korean is related to such European languages as Finnish and Magyar. The opinion that the Ural and Altaic languages are related is based on the fact that both are agglutinative languages and the belief that the origins of both can be traced to central Asia.

The Altaic group is divided into three branches: Turkic, Mongolian and Tungustic. Korean belongs to the Tungustic branch. Tungustic variants are spoken in Siberia, in Manchuria and by some 35 million Koreans, both in Korea and in Japan. Korea shares similarities in its

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[1]This part of the paper is mainly taken from the book: Korea--Its Land, People, and Culture of All Ages, Seoul, Korea, Hakwon-Sa, Ltd., Part III, People, Language, Chapter 2, Language, pp. 117-124, 1960. Some modifications and innovations were made, however, to meet the purpose of this research--especially design.

agglutinative structure with Japanese, but not with Chinese, although modified Chinese characters are used in Korean writing. The relationship of Korean and Japanese is not surprising since it is believed that Japan was settled in part by immigrants from Korea and from other areas where Tungustic languages were spoken.

Characteristics of the Language

Although the systematic study of the Korean language has not yet been completed certain characteristics have been identified.

1. Korean vowels are divided into three groups and vowel combinations tend to be made within these groups and not between them. (Such vowel harmony is a general characteristic of the Ural-Altaic languages.) The three groups are:

   a. Hard Vowels: ㅏ (a) ㅗ (o) ㅐ (ae) ㅚ (oe)

   b. Medium Vowels: ㅣ (i)

   c. Soft Vowels: ㅓ (ŏ) ㅜ (u) ㅡ (ŭ) ㅔ (e)

The vowels of groups a and c tend to combine with others within their group but to resist combination with the other group. The single vowel of the second group may combine with vowels from either of the other groups.

2. Korean words, unlike words in Indo-European languages, never begin with more than one consonant. Such English words as "strike" or "break", for example, would not occur in Korean. Further, Korean words do not begin with liquid consonants such as the English "r" or "l". Finally, Korean lacks the consonants "f" and "v". These sounds are approximated in Korean by the consonant ㅂ (p or b).

3. The most distinctive characteristic which separates Korean and other Ural-Altaic languages from Chinese or from Indo-European languages is the agglutinative structure of its grammar. In Indo-European languages grammar is indicated by modifications in words in the forms of tenses, cases and numbers. In Chinese "full" words or denotative words are never inflected and grammar is indicated by word position and by the use of word particles or "empty" words which help convey meaning. Agglutinative languages such as Korean fall between these two types of languages. Words are fixed, as in Chinese, but the "empty" words of particles become "glued" or attached to the fixed words in somewhat the same way that inflected endings are attached to word roots in Indo-European languages.

Korean Writing System: Hangul

Hangul, the Korean writing system, is phonetic, like English, rather than ideographic, like Chinese, although the characters or letters were adopted from Chinese.

Hangul was developed in Korea's "Golden Age" which was ushered in with the reign of the fourth Yi king, Sejong, in the 15th century. King Sejong, who believed that the function of written language was communication with the common people, developed an alphabetic language in order to facilitate this communication.

There are 24 letters in the Hangul alphabet--10 vowels and 14 consonants. The total number of letters in the Korean alphabet has been reduced since the period of King Sejong, with the elimination of such vowel as ㆍ and such consonants as ㅿ, ㆆ.

Hagul vowels can be formed into dipthongs and can be classified into two categories:[2]

Simple: ㅏ (a), ㅑ (ya), ㅓ (ŏ), ㅕ (yŏ), ㅗ (o), ㅛ (yo)
ㅜ (u), ㅠ (yu), ㅡ (ŭ), ㅣ (i)

Compound: ㅐ (ae), ㅒ (yae), ㅔ (e), ㅖ (ye), ㅚ (oe),
ㅟ (ui), ㅘ (wa), ㅝ (wo), ㅙ (wae), ㅞ (we)

If the simple and compound vowels are considered together, there are 21 vowels. Modern grammarians classify them as simple and dipthong vowels:

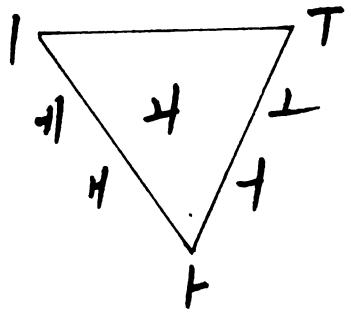
Table 2.1. Hangul Vowels

Simple-- ㅏ ㅓ ㅗ ㅜ ㅡ ㅣ ㅐ ㅔ ㅚ

Dipthongs--ㅑ ㅕ ㅛ ㅠ ㅒ ㅖ ㅟ ㅢ ㅘ
ㅝ ㅙ ㅞ

This distribution is based on the following triangular chart for the simple vowels:

Figure 2.1



Dipthongs are formed by the following principle of combination:

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[2]McGune-Reisschuer system is the best known system to romanize Korean pronounciation. Example is shown in Table 2.2.

ㅑ = ㅣ + ㅏ ; ㅕ = ㅣ + ㅓ ; ㅛ = ㅣ + ㅗ
ㅈ = ㅣ + ㅜ ; ㅒ = ㅣ + ㅐ ; ㅖ = ㅣ + ㅔ
ㅝ = ㅜ + ㅣ ; ㅢ = ㅡ + ㅣ ; ㅘ = ㅗ + ㅏ
ㅞ = ㅜ + ㅓ ; ㅙ = ㅗ + ㅐ ; ㅞ = ㅜ + ㅔ

The consonants of Hangul now in use are either simple or double:

Table 2.2. Hangul Consonants

Simple--ㄱ (k or g), ㄴ (n), ㄷ (t or d), ㄹ (r or l), ㅁ (m), ㅂ (p or b), ㅅ (s), ㅇ (silent or ng), ㅈ (ch or j), ㅊ (ch'), ㅋ (k'), ㅍ (p'), ㅎ (h), ㅌ (t)

Double--ㄲ (kk), ㄸ (tt), ㅃ (pp), ㅆ (ss), ㅉ (tch)

Word Formation in Hangul

Hangul is an alphabet but its function in word formation is not the same as the alphabet in English. In English, characters of the alphabet are used to form separate words while characters in Hangul are used to build up separate syllables. Hence Hangul may be considered a half-way point between an alphabetic and a syllabic system of writing.

A Korean word consists of one or more "boxed-in" syllables. If such a system were used in English the words "Lansing" and "Jackson" would be written as [LA N] [SI NG] and [JA CK] [SO N]. This "boxed-in" syllable formation and subsequent word formation causes a special problem in

identification in Korean handwriting because variation or "natural transformation" is caused by changing the position of a character. (See Design for Natural Transformations and Letter Position).

Korean words are generally composed of from one to four syllables, although there are a few words of seven or eight syllables. Seventy percent of the vocabulary is made up of words of two and three syllables.

Korean Handwriting

When Korean is written by hand the size and shape of individual characters within a syllable "box" vary according to letter position and other combining factors. An examination of the handwriting samples used in the present study verified the fact that letter position influences the shape and size of characters and their elements.

The characters in the Korean alphabet can be classified into three groups according to the type and number of letter positions:

Table 2.3. LP and Distribution of Ratio

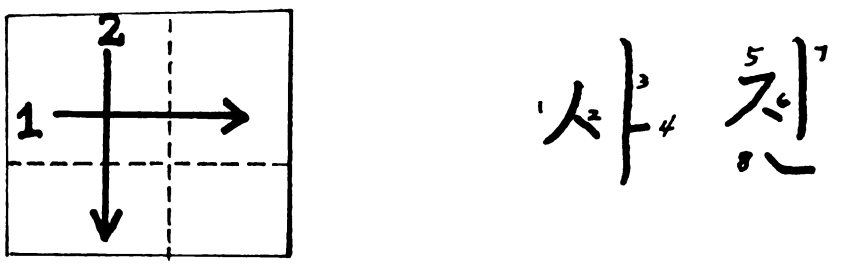
Groups	Letter Position (consonants)	Letter Position (vowels)
1	initial (ㄱ-ㅎ)	inner (ㅓ, ㅕ)
2	initial (ㄱ-ㅎ)	outer (ㅏ, ㅑ) ㅣ
2	upper (ㄱ-ㅎ)	medial ㅗ,ㅛ;ㅜ,ㅠ ㅡ
3	lower (ㄱ-ㅎ)	all vowels (ㅏ-ㅡ)

Note: 1. Vowels of the same group can be combined; vowel and consonant take opposite position in combination.
2. This rule applies to double consonants, compound consonants and dipthongs.
3. Consonants of the group 3 may be called terminal or "batchim." This is used in this study on examination of the vowel ㅏ (a).

In addition to variation introduced as a result of position in the syllable "box" there is also variation resulting from other factors. For example, when a syllable is at the end of a sentence or paragraph, its characters tend to be either increased or reduced in size.

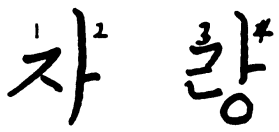
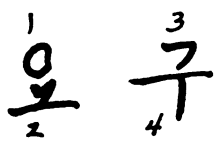
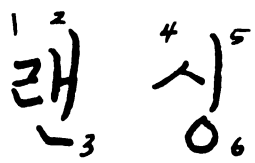
As indicated above, writing is done in an imaginary "box" for each syllable; syllables are combined into rectangular words. Elements of a character are either predominantly horizontal or predominantly vertical; vertical strokes are made from top to bottom and horizontal strokes are made from left to right.

Figure 2.2. Illustration for Korean Writing Step



The position of a vowel in a syllable can cause modification in these basic strokes. For example, the writing steps for a consonant consist first of a vertical movement and then of a horizontal movement if the consonant is combined in a syllable with vowels in inner or outer positions; no horizontal movement is needed if it is combined with vowels in the medial position. The relationships between consonants and vowels in syllable and word formation are shown below.

Table 2.4. Syllable and Word Formation

Groups	Examples	Specifications
1		1=initial consonant 2=outer vowel 3=initial consonant 4-outer vowel
2		1=initial consonant 2-outer vowel
3		1=upper consonant 2=medial vowel 3=upper consonant 4=medial vowel
4		1=initial consonant 2=outer vowel 3=lower consonant 4=initial consonant 5=outer vowel 6=lower consonant

The same writing steps are used in the formation of sentences and paragraphs. Traditional style has a top-to-bottom direction for vertical movements and a right-to-left direction for horizontal movements; there is seldom any top-to-bottom direction of vertical movement combined with left-to-right horizontal movement. The Western style is adopted in the copybook style of writing; only 2 out of 78 standard writings used in the present study were written in the traditional way.

As in Chinese and Japanese, Hangul script is modelled after the brush-stroke tradition--the initial and terminal edges of each stroke are usually pointed while the middle part is rounded. Adherence

to this method depends not only on practice but also on the skill of the writer. (Individuals who are skilled in writing Chinese characters usually write Korean characters in the traditional style). Hence, presence or absence of the traditional style has some evidential value.

Connecting strokes are more evident in vertical writing than in horizontal writing. However, in the standard writing pattern no connecting strokes are to be made in either case and, if they are present, they are the result of either speed of writing or individual habit. (It should be noted that some of the old style brush writing have connecting strokes as a standard form, particularly in vertical writing.)

In the present study individual "elements" which include strokes and angles between strokes, are the basic units of study. Neither stroke widths or connecting strokes are examined, although both might be used in further study.

CHAPTER III

METHODOLOGY

As indicated in Chapter I, the present study was designed to explore the usefulness of inferential statistics in the area of handwriting identification. More specifically, the object of the study was to determine whether samples of handwriting made by different individuals whose identity was known could be distinguished quantitatively and objectively through the use of statistical analysis and, as a corrolary, to determine if two samples of writing known to be made by the same individual could be shown by similar methods, to have been made by the same writer. If these similarities and differences could be demonstrated statistically then the application of statistical methods in handwriting analysis could fruitfully be made the object of further study and refinement.

The present study was patterned after typical research in the biological and social sciences.[1] Random samples of handwriting were used, objective methods of measurement were developed and appropriate statistical tests were applied to the measurements. The present chapter discussed these aspects of the study while the following chapter presents the analysis of the data and discusses the findings of the study.

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[1]For a discussion of social science research methodology see Claire Selltiz et al, Research Methods in Social Relations, 2nd ed. New York: Henry Holt, 1959; Pauline Young, Scientific Social Surveys and Research, Englewood Cliffs, N.J.: Prentice-Hall, 1956.

Inferential Statistics and Handwriting Identification

The present section presents a more detailed examination of the relevance of inferential statistics to handwriting identification, a question which was discussed briefly in the first chapter.

In the biological and social sciences (and in other fields as well) researchers are often confronted with the necessity, because of limited time and resources, of conducting research with samples rather than with universes.[2] Such an approach poses problems in making generalizations about the universe from which the sample was drawn since samples drawn from heterogeneous universes (i.e., universes in which the element being measured exhibits variability) are unlikely to coincide in any summary measurement, such as the mean, with the universe. A series of samples drawn from a particular universe will exhibit "sampling variation" or "sampling error"; a descriptive statistic, such as the mean, will vary from sample to sample and the means of most of the samples will not be the same as the mean of the universe.[3]

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[2] In statistical usage the term "universe" refers to all individuals of a particular category (or more specifically, to all measurements of a particular class, such as the heights of all residents of Lansing, Michigan). If all individuals in a universe are measured, the resulting set of measurements is called a "census." A smaller set of individuals selected from a universe is called a "sample." Walker and Lev, op. cit., p. 1.

[3] See Walker and Lev, op. cit., Chapter I; Hubert M. Blalock, Social Statistics, New York: McGraw-Hill, 1960, Chapter 8; Celeste McCollough and Loche Van Atta, Statistical Concepts, New York: McGraw-Hill, 1963, Chaps. 11 and 12.

The factor of sampling variability gives rise to a common problem in which the investigator has two (or more) samples and wishes to determine whether they were drawn from the same universe. In all likelihood the samples will not be the same in any of the descriptive statistics (e.g., mean, standard deviation or median) which might be computed for them. Inferential statistics allow the investigator to determine, within a specified probability of error, whether the two samples were drawn from different universes, with different characteristics, or from the same universe. In the latter case the differences in the samples can be attributed to sampling variability. The investigator has a choice of a variety of measures--chi square, t-test, F-test and others--which are applicable to different forms of data but which are similar in that they permit inferences to be made with known probabilities of error.

As indicated previously, the problem of handwriting identification closely parallels this type of problem. All of the writings of a given individual can be conceived of as a universe of measurement while any particular piece of writing can be conceived of as a sample from this universe. Because of the factor of variation in writing two samples of writing made by a particular individual will probably show differences in some measurable characteristic. such as the mean length of an element of some character. On the other hand writings made by different individuals often show similarities as well as differences. The problem confronting the examiner is the question of determining an appropriate weighting of similarities and differences in order to make a decision about authorship. Such

a problem can be approached within the logical framework of inferential statistics since the problem is one of determining whether the writings were drawn from the same universe (that is, made by the same individual) and are different because of sampling variability or whether they were drawn from different universes (i.e., made by different writers). While inferential statistics does not permit such a decision to be made with certainty it does allow it to be made with a specified probability of error. If this technique can be applied to handwriting analysis it should be a useful method in objectively evaluating similarity and dissimilarity.

The present study was based on the use of two inferential statistical tests--the F test and the t-test--applied to measurements of several micro-elements of handwritings made by a sample of Korean students. The present chapter discusses the sample and the techniques of measurement. The analysis of the measurements is discussed in the following chapter.

The Preliminary Investigation

One branch of handwriting identification involves the classification of writing types, on the basis of qualitative patterns or configurations, into broad categories or "class patterns." It can be seen that the analysis of writing within a particular "class pattern" provides the most rigorous test of the power of inferential statistics since the differences between writings within the same class pattern will be smaller than differences between writings in different classes. Since the present study was intended as a test

of the relevance of inferential statistics in handwriting identification it was decided to use samples drawn from the same class pattern for analysis.

In order to identify the class patterns within Korean writing, a sample text, which was to be copied in order to provide samples of writing, was developed. (Appendix 1) The text for the letter was designed to meet two criteria: inclusion of as many characters as possible and repeated use of high frequency characters. The sample texts were sent to a sample of 200 Korean college students studying in the United States. The sample was drawn randomly from two directories of students supplied by the Consulates General in New York and San Francisco who have jurisdiction over the Korean student population in the United States. The 78 students who returned the letters included both graduate and undergraduate students and had a mean age of 25.7.

For the final study writings from the personal correspondence file of the researcher collected from 1954-1962 were used. The sample included ten letters, each chosen randomly from a total of 490 letters, for ten individuals.

Selection of Characters for Study

Since it was beyond the scope of the present study to analyze all of the characters found in the sample writings it was necessary to select certain characters for analysis. For the present research a consonant ㅅ (j) and a vowel ㅏ (a) were chosen for a study of class patterns and the vowel was selected for measurement and statistical analysis. In choosing the two characters four criteria were used:

high frequency of usage in ordinary language, maximum number of strokes, common origin and persistence of class patterns. The pre-test showed that the consonant had 25 class patterns and the vowel 18. (Appendix 2)

As indicated previously a letter in Korean writing will vary according to its position in a syllable and according to the letters with which it combines. These variations are shown in Table 3.1.

Table 3.1. Assignment of Numbers to Letter Positions

Consonants		Vowels			
Numbers[1]	Letter Positions[2]	Numbers	Letter Positions	Numbers	Letter Positions
1	initial	4	inner	7	inner
2	upper	5	outer	8	outer
3	lower	6	medial	9	medial

1. These numbers appear in the classification code.
2. Letter Positions, 7, 8, 9 are similar to 4, 5 and 6 respectively with an exception that 4, 5 and 6 have lower consonants or "Batchim" additionally.
3. The consonants may be combined with any one of the letter positions specified hereon.
4. For the exemplary study in this paper, Letter Position 9 of the vowel along with Class Pattern 1 was used for measurement.
5. See Korean Writing System for Syllable and Word Formation.

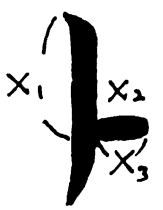
In order to further limit the variation in the letter studied analysis was limited to letters occurring within a single position as well as within a single class pattern. In the present study, then, thw vowel ㅏ (a) occurring in position 9 of class pattern 1 was measured and analyzed.

Types of Measurement

Since Korean writing is linear, with the exception of a few circular characters, two types of measurement can be made: measurement of stroke length and measurement of the angle between strokes. In addition the writing of many individuals show some curvature in the normally linear strokes. The measurement of this type of curvature was beyond the technical means available to the researcher so measurement was confined to length, angle and ratio between lengths.

In the statistical analysis the vowel ㅏ (a) was measured and analyzed. This vowel has three elements which can be measured: the vertical stroke (X1), the horizontal stroke (X3) and the angle between them (X2). (See Appendix 3)

Figure 3.1



The ratio (X1/X3) can also be analyzed. All of these measures were used in the analysis.

Although the operation of measuring straight lines and angles would appear to be simple the factor of linear irregularity found in handwritten characters requires the adoption and systematic use of measurement rules.[4]

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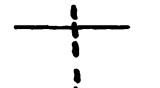
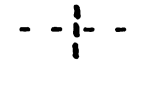
[4]See Appendix 3. Application of the measurement plate shows how linear irregularity is compensated by consistent use of measurement rules.

The Measuring Instrument

A special measuring instrument was developed by the writer for use in the study. In order to make the instrument useful for further studies of Korean writing it was decided to design it in such a way as to make possible the measurement of any of the Korean characters. An examination of Korean letters indicated that they can be classified into a few general shapes as indicated in Figure 3.2.

Figure 3.2. Basic Pattern Chart

Groups[1]	Consonants	Basic Pattern	Vowels	Basic Pattern[2]
I	ㅈ, ㅊ, ㅅ		ㅏ(ㅑ); ㅓ(ㅕ)[3]	
II	ㅇ, ㅎ		ㅗ(ㅛ); ㅜ(ㅠ)	
III	ㄱ(ㅋ); ㄴ, ㄷ(ㅌ); ㄹ		ㅡ, ㅣ	
IV	ㅁ, (ㅂ): (ㅍ)			

1. Grouping based on common origin of the stroke and basic design.
2. - - - - denotes movable line, and ——— denotes basic stable line.
3. ( ) sub-grouping.

The basic patterns shown in Figure 3.2, square, triangle, and circle, were included in the measuring instrument. In order to insure flexibility in measurement these were incorporated in the instrument as concentric squares, wedges and circles. In order to avoid crowding, some modification of these patterns was made. Concentric circles were used as the basic unit of measurement. In the upper half of the plate concentric squares were modified into parallel lines which corresponded

to the units of the concentric circles. Concentric wedges, as such, were not used but the parallel lines and the lines dissecting the concentric circles formed wedges which could be used for measurement. The lower half of the plate was divided into 16 parts, with each part equaling 11.25 degrees. The entire circle was divided into eight sections, each of 45 degrees, so that wedge-shaped consonants and vowels could be measured. (Appendix 4)

The instrument described above was first drawn in enlarged size with the largest circle approximately 43 cm in diameter. The drawing was then reduced to the smallest size possible without blurring of lines. Such a reduction in size was necessary in order to insure the maximum accuracy in measurement. In the reduced drawing the largest circle was 3 cm in diameter; hence, the drawing was reduced to 1/14 of its original size.

Kodak microfilm was used in preparing the reduced plate. Kodak lantern slides were found to be the best for prints, since they are durable, transparent and easy to use. It should be noted that the thickness of the slide can cause visual distortion unless the slide is viewed directly from above.

In use the slide was placed over the element to be measured and measurement was made in the arbitrary units on the slide. In the development of the instrument no effort was made to use absolute units such as inches or centimeters. While the use of absolute units would be desirable for police records and similar uses it was

felt that it was not necessary in this study because the same instrument was used for all observations and, as a result, the unit of measurement was held constant.

CHAPTER IV

ANALYSIS AND FINDINGS

The statistical analysis discussed in this chapter was made using measurements of the vertical stroke (X1), the horizontal stroke (X2) and the angle between strokes (X3) of the Korean vowel ㅏ (a). The writings of eight Korean students were the source of the characters measured. Two sets of samples from these writings were analyzed. In the first set 50 characters were selected at random from each of these writings; in the second set 10 characters were selected randomly. All of the characters used in the analysis were originally classified in class pattern 1. The purpose of the analysis was to determine whether the authorship of these samples could be determined statistically.

The Major Analysis

When pairs of writings are compared in handwriting analysis there are two possibilities: either the writings were made by the same individual or they were made by different individuals. The problem confronting the handwriting examiner is to determine which of these alternatives is true. If statistical analysis is to be useful in problems of this sort it must be equally capable of determining

similarity or difference. In the part of the statistical analysis discussed in this section both situations were tested. For the test of difference each individual was compared with every other individual for a total of 28 comparisons. For this test, samples of 50 characters were used. For the test of similarity, each sample was divided randomly into two samples of 25 and comparisons were made between these pairs of samples for each individual.

The statistical test used was the t-test for differences between means. This test was selected since the data used in the analysis meets the necessary conditions of interval scale, normal distribution and equal variance. Providing that these conditions can be met, the t-test is the most sensitive statistical test which can be used for comparison of pairs of samples.[1]

In statistical tests used to determine whether two samples were drawn from the same universe it is the usual practice to phrase this question in the form of a "null hypothesis" (symbolized as H_o).

H_o: There is no significant difference between the means of the two samples. The null hypothesis can be paraphrased in the following way: "Any difference between the means of the two samples is the result of sampling variability and not the result of the fact that the samples were drawn from different universes." After stating the null hypothesis the statistician establishes a "region of rejection" or "critical region" which is stated in probability terms. If the researcher selects a probability of .05 as the critical

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[1] Blaylock, op. cit., Chapt. 13.

region, for example, he will reject the null hypothesis if the difference between his samples could have occurred by chance less than 5 times out of 100, as a result of sampling variability. If he rejects the null hypothesis he accepts the alternative hypothesis that the samples were drawn from different universes. If the difference between his samples could have occurred more than 5 times out of 100 as the result of sampling variability he accepts the null hypothesis and assumes that sampling variability did, in fact, cause the difference. The choice of a critical region depends on the nature of the study (and sometimes on how conservative the researcher is). A statistical test, such as the t-test, is used to determine the probability of the difference occurring as a result of sampling variability.

In the various analyses discussed in this chapter the following null hypothesis was used:

H_o: Pairs of writing samples were made by the same individual. The critical region was set at .05 and two-tailed tests were used in all cases.[2] In terms of the present analysis the acceptance or rejection of the null hypothesis must be interpreted in two ways. In tests where the samples being compared were made by different individuals, a probability which allows the null hypothesis to be rejected means that the identification has been made correctly--that the writings are from different universes. If the null hypothesis must

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[2]A discussion of one and two-tailed tests will be presented later in the chapter.

be accepted an incorrect identification has been made. Where the samples being compared were made by the same individual the reverse is true--the rejection of the null hypothesis means an incorrect identification and the acceptance of the null hypothesis means that the identification has been made correctly since the samples were, in fact, drawn from the same universe.

The results for pairs of samples made by different individuals are found in Table 4.1 and the results for pairs of samples made by the same individual are found in Tables 4.2 and 4.3. In these tables incorrect identifications are indicated by asterisks. Table 4.4 summarizes the results of both sets of tests.

Tests Using Small Samples

In practical handwriting analysis the examiner may have available only a small piece of writing with a relatively limited number of characters. In order to determine the efficiency of statistical analysis in situations of this kind statistical tests were made between pairs of samples, made by different individuals, with 10 characters in each sample. The null hypothesis, region of rejection and statistical test were the same as for the larger samples. Table 4.7 presents the results of this test. For the smaller samples 60.71 percent were correct for X1, 35.71 percent for X2 and 39.28 percent for X3.[3]

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[3]When groups of small samples are analyzed it is considered good statistical practice to compute an F-test for the entire set of samples. For the samples in this part of the study the samples for all three elements were significantly different at the .01 level.

Table 4.1. T-Tests for Pairs of Samples for Different Writers (N=50)

	t		
Pair	X_1	X_2	X_3
1-2	5.55	7.16	.65*
1-3	1.00*(a)	4.84	1.30*
1-4	.65*	5.62	2.40
1-5	14.86	26.66	7.36
1-6	22.88	2.17	.23*
1-7	2.15	1.38*	.70*
1-8	7.92	10.69	3.20
2-3	26.20	11.59	2.78
2-4	5.76	.93*	4.35
2-5	9.81	16.07	8.55
2-6	18.80	9.06	1.21*
2-7	1.68*	4.27	.05*
2-8	3.96	3.38	2.55
3-4	1.57*	8.66	1.57*
3-5	15.77	1.74*	10.50
3-6	25.64	2.71	1.57*
3-7	2.78	5.19	2.35
3-8	9.00	14.97	5.29
4-5	13.08	10.45	11.60
4-6	22.51	6.96	3.14
4-7	1.75*	4.01	3.64
4-8	7.17	1.34*	8.00
5-6	14.42	5.19	9.40
5-7	6.97	7.27	7.72
5-8	3.89	20.25	5.45
6-7	15.33	3.04	1.05*
6-8	12.48	12.83	4.85
7-8	4.02	7.03	2.93

d.f.= 49
(a) = incorrect identifications and marked with an asterisk.

t.05= 2.02
t.01= 2.70
t.001=3.55

Table 4.2. Means and Standard Deviations for Pairs of Samples for the Same Individual (N=25)

Individual	X_1				X_2				X_3			
	$\bar{X}$	s	$\bar{X}$	s	$\bar{X}$	s	$\bar{X}$	s	$\bar{X}$	s	$\bar{X}$	s
1	3.48	1.19	3.44	.83	5.96	.87	6.00	.98	2.38	.78	2.76	1.44
2	4.88	1.10	4.03	1.51	6.92	1.74	7.72	1.69	2.88	.79	2.52	.69
3	3.30	1.05	3.22	.87	5.00	.98	5.12	.99	2.08	.66	2.54	.84
4	3.80	1.21	3.38	1.08	8.24	1.56	6.94	1.82	1.88	.49	2.30	.74
5	6.24	1.25	7.22	1.08	4.64	.49	4.92	.56	4.26	.98	4.56	1.65
6	8.64	.92	10.70	1.20	5.80	.89	5.36	.93	2.32	.60	2.72	.64
7	4.60	2.00	3.70	6.93	6.12	1.55	6.48	1.14	2.72	1.04	2.70	.99
8	5.66	1.30	5.54	1.80	7.72	1.08	8.24	.77	3.20	.95	3.22	.85

Table 4.3. T-Tests for Pairs of Samples for the Same Writers (N=25)

Individual	X_1	X_2	X_3
1	.13	.15	1.19
2	2.23*(a)	1.63	1.73
3	.29	.43	2.19*
4	1.31	2.70*	2.33*
5	2.80*	.45	.79
6	6.65*	1.69	2.02
7	1.61	.95	.07
8	.27	2.00	.08

d.f.= .24; t.05= 2.06; t.01= 2.80; t.001= 3.55

(a) incorrect identifications are indicated by an asterisk

Table 4.4. Correct Identification

Type	X_1 N	X_1 %	X_2 N	X_2 %	X_3 N	X_3 %	Total N
Different Individuals	23	82.14	24	85.71	19	67.85	28
Same Individual	5	62.50	7	87.50	6	75.00	8
Both Types	28	77.77	31	86.11	25	69.44	36

Table 4.5. Means and Standard Deviations for Small Samples (N=10)

Individual	X_1		X_2		X_3	
	$\bar{X}$	s	$\bar{X}$	s	$\bar{X}$	s
1	3.55	1.19	2.05	.47	1.80	.72
2	4.40	1.09	2.30	1.03	2.40	1.19
3	2.80	.95	2.10	.89	1.68	.96
4	4.95	1.69	1.95	.57	2.80	1.49
5	5.93	1.02	3.60	1.09	1.81	.58
6	9.45	1.71	2.15	.59	4.64	1.17
7	3.95	1.89	3.75	2.45	1.73	1.26
8	2.85	1.24	2.25	.51	1.35	.62

Discussion of Findings

An examination of the results of the analysis points to two general conclusions about the use of statistical inference in handwriting analysis. First, it is evident that, in the case of samples of writing which are fairly large, a rather high degree of accuracy in determining similarity and difference is possible. As the sample size decreases accuracy also decreases.

Second, it must be stressed that the technique is not completely accurate for any of the elements measured even for the larger samples. Because a high degree of accuracy is vital in the legal application of handwriting analysis, methods for improvement must be developed. Accuracy may be increased in part by combining macro-analysis with micro-analysis, in part by improvements in the micro-analysis. A detailed analysis of the statistical findings suggest several ways in which micro-analysis can be improved.

1. The use of more than one character as the basis for analysis. An examination of the mean measurements in Table 4.6 shows that some of the individuals are rather close in their mean measurements for a particular element. Normal handwriting falls within a restricted size range and it can be expected that a number of individuals will have the same mean size and range of variability in a given letter element. The figures in Table 4.1 indicate, however, that there is no pair of individuals which is not significantly different in at least one of the measurements. This fact indicates that individuals may be more unique in their overall writing than they are in terms of a single character and suggests that more than one character should be analyzed in applied handwriting examination.

Table 4.6. Means and Standard Deviations for Individual Samples (N=50)

Individual	X_1		X_2		X_3	
	$\bar{X}$	s	$\bar{X}$	s	$\bar{X}$	s
1	3.46	1.06	5.98	.91	2.57	1.17
2	4.57	.94	7.32	.97	2.70	.76
3	3.26	.97	5.06	.99	2.31	.79
4	3.59	1.17	7.59	1.81	2.09	.66
5	6.73	1.26	4.78	.55	4.41	1.28
6	9.67	1.48	5.58	.94	2.53	.61
7	4.15	2.01	6.30	1.37	2.71	1.01
8	5.60	1.57	7.98	.97	3.21	.84

2. More accurate measurement. Some of the apparent similarity between individuals may be the result of inaccuracy or insufficient refinement in measurement. It can be suggested that improvements should be made in the instrument in order to permit more precise measurement and in order to permit the measurement of curvature which is an important part of the characteristics of a stroke.

3. Control of Type I and Type II errors.[4] Because statistical inference is based on probability rather than certainty it is possible that a decision about the null hypothesis may be in error. There are two kinds of error which can be made:

(a) Type I error - the rejection of the null hypothesis when it should be accepted. In terms of handwriting analysis this means that the examiner concludes that the writing was made by different individuals when it was actually made by the same individual. The errors found in Table 4.3 are of this type.

(b) Type II error - the acceptance of the null hypothesis when it should be rejected. Again, in terms of handwriting analysis this means that the examiner concludes that the writing was made by the same individual when, in fact, it was made by different individuals. Errors in Tables 4.1 and 4.7 are of this sort.

There are several approaches to increased identification accuracy based on an analysis of the two types of errors. Type I error can be reduced simply by raising the region of rejection. If the region of rejection were set at .01 instead of at .05 (which was used in this study) only one error instead of 6 would have occurred

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[4]For a discussion of types of error and the power efficiency of statistical tests see Blaylock, op. cit., Chapter 14.

Table 4.7. T Tests for Pairs of Small Samples for Different Writers (N=10)

Pair	t X_1	X_2	X_3
1-2	1.66*	.70*	1.37*
1-3	1.55*	.16*	.31*
1-4	2.14*	.43*	1.91*
1-5	4.80	4.13	.34*
1-6	8.95	.42*	6.54
1-7	.56*	2.15	.12*
1-8	1.28*	.91*	1.50*
2-3	3.49	.47*	1.48*
2-4	.86*	.99*	.66*
2-5	3.24	2.74	1.43*
2-6	7.88	.40*	4.25
2-7	.65*	1.72*	1.22*
2-8	2.96	1.37*	2.48
3-4	3.49	.45*	1.99*
3-5	7.08	3.38	.34*
3-6	10.74	.15*	6.19
3-7	1.72*	2.00*	1.00*
3-8	.010*	4.62	.91*
4-5	1.57*	4.24	1.96*
4-6	5.91	.76*	3.07
4-7	1.35*	2.26	4.73
4-8	3.15	1.25*	4.84
5-6	5.60	3.69	3.69
5-7	2.92	.18*	1.76*
5-8	6.05	.35*	3.50
6-7	6.82	3.54	3.70
6-8	9.87	3.70	3.54
7-8	2.45	1.89*	1.89*

d.f.= 9 t.05= 2.26
t.01= 3.25
t.001=4.78

(a) asterisks indicate incorrect identification

in comparisons of writings made by the same individual as shown in Table 4.3. This would, however, have increased the number of Type II errors in Table 4.1 from 18 to 25.

One method of reducing both types of error is to raise the region of rejection in order to reduce a Type I error and increase the sample size in order to reduce a Type II error. The reduction of Type II error by increasing sample size can be seen in the improvement in accuracy of samples of 50, Table 4.1, over samples of 10 in Table 4.7. It can be suggested then that the examiner use a high region of rejection (at least .01) and use the largest sample possible.

An additional reduction in Type II error can be made by using a one-tailed test. In a two tailed test, the type used in this study, the direction of differences between means was not specified. More specifically, when two samples were compared the test was made to include both the probability that the sample mean was below the universe mean and the probability that the sample mean was above the universe mean. If the universe mean is known, then a one-tailed test in which the direction of the sample mean is specified. Such a test will have a smaller probability of Type II error than a one-tailed test for the same sample size. The use of a one-tailed test might be possible if a sample of questioned writing is being compared with a large standard writing of known authorship. This situation might be possible if criminal investigation bureaus kept quantitative records of writing in the same way that fingerprint records are kept.[5]

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[5] Ibid., Chapter 14.

It is apparent that statistical inference can determine the identity of writing with a relatively high degree of accuracy although not with absolute certainty. The probability of error in identification can be greatly reduced by the use of methods suggested above.

CHAPTER V

CONCLUSIONS

The research reported in this paper was an exploratory study of the possibility of using inferential statistical methods in handwriting analysis. Two inherent characteristics of handwriting--variation within the writings of a single individual and overlap in writings made by different individuals--make handwriting identification problematic. Current methods of analysis do not completely solve the problems presented by these factors because, while they do consider similarity and difference, they do not provide objective criteria for deciding how much similarity there must be before it can be concluded that samples of writing were made by the same person or how much dissimilarity there must be before it can be concluded that samples were made by different persons. The technique of inferential statistics was developed in order to solve the same type of problem in other areas of inquiry and an examination of the conceptual and mathematical structure of this technique suggests that it can be legitimately used in the area of handwriting analysis.

The present study was limited in scope in several ways. The study was based on the measurement of elements of a single character. The measuring instrument developed by the writer for the study was restricted to line and angular measurement and was not capable of

measuring stroke curvature. Small samples were used. In spite of these limitations the statistical tests used led to correct identifications in 69 percent of the cases for the least discriminating element and in 86 percent of the cases for the most discriminating element. Further, it has been shown that the accuracy of identification based on a single element can be improved by increases in sample size and by changing the region of rejection of the null hypothesis. The findings, then, seem to demonstrate that the techniques of statistical inference hold great promise for improvements in handwriting identification.

The present study was exploratory and was not designed to develop a finished method of identification. The development of a finished method which can be used in criminal investigation can only result from continued research in this area. On the basis of the preliminary research made for the present study and the findings reported in the preceeding chapter the writer would suggest that research for the development of a mature statistical handwriting identification technique should include the following things:

1. The development of better measuring instruments. It would be particularly desirable to develop instruments which could measure curvature and stroke width and which were calibrated in standard linear measurements such as fractions of a millimeter. In the area of measurement, methods for controlling the measurement error, which would vary from examiner to examiner should be developed.

2. The combination of micro-analysis and macro-analysis. The analysis of class-patterns--the overall stylistic characteristics of writing--should be combined with the measurement of character elements. The development of a technique for quantifying macro-characteristics would be an important step in the development of a precise handwriting system.

3. The study of writing in various languages. The present study was based on the Korean alphabet. If the technique of statistical analysis is to have general applicability, the factors of variability and coexistence of similarity must be studied in other languages. Although it can be assumed that the methods used in the present study are applicable for other languages such an assumption must be tested before a universal system of identification can be developed.

4. The investigation of statistical analysis in disguised writing. The present study made no attempt to examine disguised writing. It is apparent that a great number of the cases processed by handwriting examiners may include disguised writing. For this reason the usefulness of statistical analysis in disguised writing must be thoroughly investigated.

5. The development of techniques for multiple character analysis. One of the findings of the present study suggested that identification can be more accurate if it is based on the examination of several characters. A mature identification system should probably include techniques for quantitatively combining various elements.

6. Exhaustive study of writing variation and coexistence. Before statistical identification methods can be completely developed more data concerning patterns of variability, overlap of characteristics and internal combinations must be collected and analyzed. In other words, a great deal more must be known about the universe of handwriting before a mature technique can be developed. This could be facilitated if criminal investigation departments in various countries would collect and classify handwriting specimens in the same way that they collect fingerprints.

The writer feels that the use of statistical methods holds great promise for handwriting identification and is hopeful that more research in this area can lead to the development of a scientifically and legally acceptable handwriting identification system.

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Appendix 1

Sample Text

"어머니 날"에 부치는 글

어머님께:

오늘 "어머니 날"을 맞이하여 새삼스러히 어머님의 모습과 함께 향수가 자자듭니다. 어머니날이 돌아오면 해마다 무엇으로 어머님을 즐겁게 해드릴가 궁리만 하며 날을 보내고 해를 보내곤 했었는데, 더욱이 이렇게 수십만리 이방에서 무엇으로 기쁘게 해드릴수 있으리까마는, 생각하면 어머님의 끝없이 무르하고 가없이 큰 사랑에 티끌만한 정을 표시함으로써 잠시 보답하려는 심사가 몹시 죽스러워 하오이다.

때로 사람이란 퍽이나 무심한것으로 머리에 푸른물이 있고 대기에 풍인에 안기어 비로소 기쁘고 즐거운 삶이 있음을 잊듯이 이제 지우 탈없이 의하여 이날을 맞음에 어머님의 사랑과 은덕을 감사하기 앞서 도리려 변변치못한 연전 부끄러움이 먼저 앞장을 서게 됩니다.

고로의 소리와 함께 신비스러운 생명을 받아가지고 어머니로부터 태어나 가는 빛가 자라고 굳어지고 이제는 제법 어른의 행세를 하는 그늘까지 한결같은 사랑과 양육과 추호의 끝이없는 어머님의 상량은 우리나라 속담에 "어른 백은 어버이 예순된 아들없고 내건는다"는 말에서도 잘 표현되고 있어라.

언제나 사랑하오면 "어머니!"소리에, "아레요"를 하시는 어머님의 분마리가 없으며, 마음을 곱시 같이 지르려가는데 돌아오시는 것는 어머님 기다리는 어린애처럼 허전한 마음, 갑과 같이 못한데서 오는 적적감, 또한 서글픔로 어머님 앞에서 마는 5원의 차는 구름 벗겨지듯 순식간에 사라지고 어머님의 사랑속에 자랑스러운 딸이 되어 버리나이다. 정영이것은 차마리 신비한 사랑이 아니오리까 ····

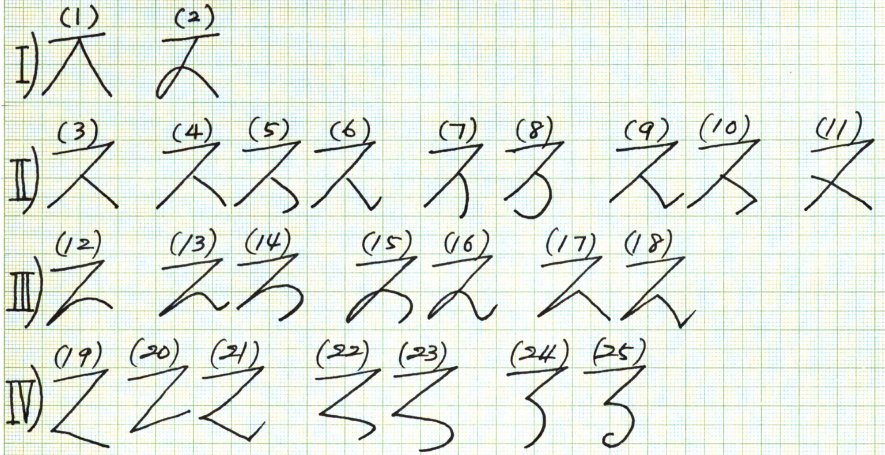
아상은 <u>한이홍신</u> 1961년 5월 10일에 실린
고용복 씨의 "어머니 날에 부치는 글"에서
옮겨 쓴 것임

Appendix 2

Major Divisions of Class Pattern

3. On horizontal line, single space music and dynamics

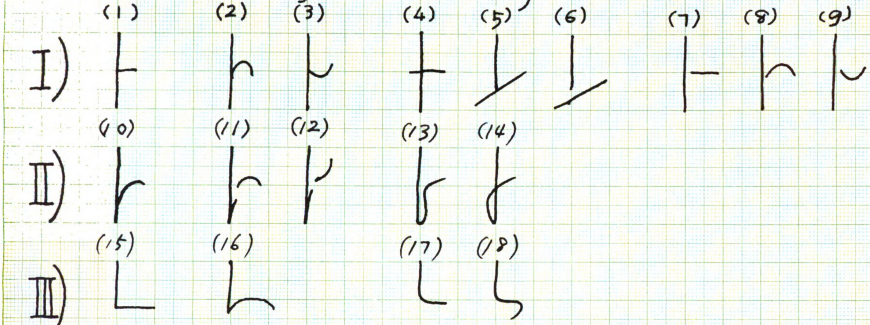
Major Divisions of Class Pattern



Notes:

1. Roman numerals denote primary grouping based on common origin of the stroke.
2. Arabian numerals denote sub-grouping as used in the major division.
3. On horizontal line, single space means sub-grouping and no space between class patterns means further

Major Divisions* of Class Pattern



Notes: 1. Roman numerals = primary grouping
2. Arabian numerals = sub-grouping as used in the M-D*
3. Horizontal line = family based on common origin of the stroke
   1) Single space = sub-grouping
   2) Double space = further grouping

Appendix 3

Application of the Measurement Plate

In the measurement of the lines and angles of the character analyzed in this study the following rules have been used:

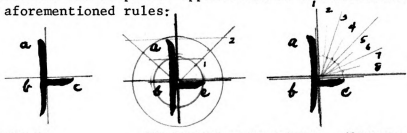
1. Maximum Extension Rule (MER)--The measuring instrument is placed on the line to be measured.

2. Inner Line Rule (ILR)--The measuring instrument is placed inside the line to be measured.

3. Maximum Angle Rule (MAR)--As in the maximum extension rule the measuring instrument is placed on the two lines which intersect.

4. Inner Angle Rule (IAR)--the instrument is placed inside the angle to be measured.

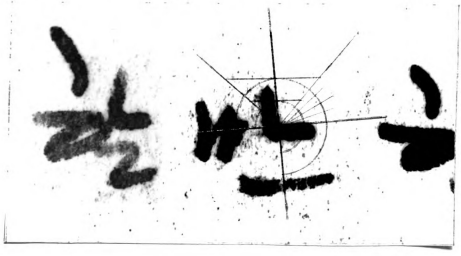
To illustrate the steps for application of the measurement plate and the aforementioned rules:



Note: (1) LINE-UP (2) LINEAR MEASUREMENT ab=X1=2 bc=X2=1 (3) ANGULAR MEASUREMENT abc=X3=8

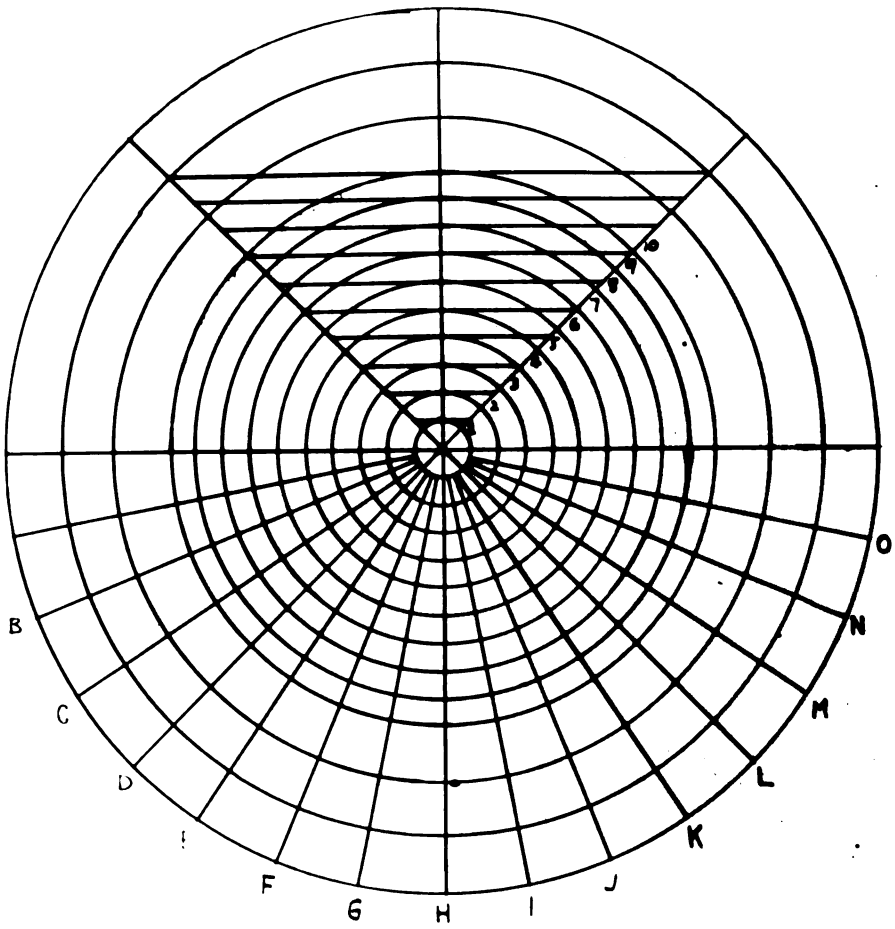
red lines=lines drawn according to the rules
black lines=lines on the plate

All three steps may be illustrated:

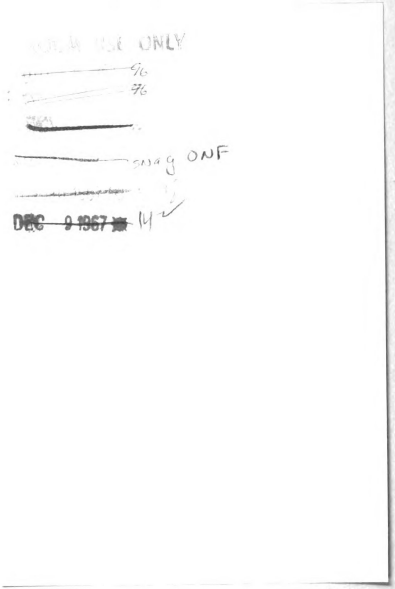


Appendix 4

Measurement Plate (Enlarged Positive)



10 Cm

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