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Fingerprint Patterns and the Analysis of Gender Differences in the Patterns Based on the *U* Test

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Abstract The testing and frequency distribution analysis of African American fingerprint patterns (loop, whorl, and arch) was conducted. It was shown that loops are the most common, whorls are the second most common, and arches are the least common with a very small percentage (4.33%). Most loops are ulnar loops while only 4.47% loops are radial loops. Of the total arches, 61.54% arches are plain arches and 38.46% arches are tented arches. A comparative study of gender difference in African American fingerprint patterns was conducted using a non-parametric method based on the *U* test. The *U* test results show that there is no significant gender difference in fingerprint patterns between African American males and females at the 0.05 level of significance.

Keywords: *fingerprint system, information technology, fingerprint pattern, loop, whorl, arch, flat fingerprint, rolled fingerprint, slap fingerprint, U test*

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1. Introduction

Fingerprints have had a lot of forensic and commercial applications. Recent advances in automated fingerprint identification technology, coupled with the growing need for reliable person identification have resulted in an increased use of fingerprints in both government and civilian applications such as border control, employment background checks, and secure facility access [1].

Automated Fingerprint Identification Systems (AFISs) have played an important role in many forensics and civilian applications. There are two main types of searches in forensics AFIS: ten print search and latent search. In ten print search, the rolled or plain (flat) fingerprints of the 10 fingers of a subject are searched against the fingerprint database of known persons. In latent search, a latent print developed from a crime scene is searched against the fingerprint database of known persons [1]. The Federal Bureau of Investigation's (FBI) Integrated Automated Fingerprint Identification System (IAFIS) is an automated ten-print and latent fingerprint identification system as well as criminal history file [2]. The Department of State (DOS) and Department of Homeland Security (DHS) US-VISIT program tried to migrate from two-finger capture to ten-print capture [3]. The additional biometric information could be used to check fingerprints against important databases, such as IAFIS [4].

IDENT (INS's Automated Biometric Identification System), used to monitor illegal border crossing activity, was designed to identify the recidivists among illegal border crossers for possible criminal prosecution. At border crossings (ports of entry) and border patrol stations, INS agents capture flat images of individuals' right and left index fingers to check the identity and criminal background of aliens attempting to enter the United States [2]. A study conducted by the Criminal Justice Information Services Division of the Federal Bureau of Investigation (FBI) demonstrated a significant drop in performance when comparing 10-print flats against rolled prints in IAFIS. This was attributed to the system's inability to accurately process flat prints since the system was tuned to process rolled prints [5]. Another study conducted by Mitretek Systems analyzed the issues affecting the integration of FBI's IAFIS[1] (that uses 10 rolled prints) with the INS IDENT system[2] (that uses two flat prints). The study arrived at the following conclusions [2]: 1) two-finger searches of IDENT-quality fingerprints cannot achieve adequate performance against the existing IAFIS without a dramatic increase in processing resources; 2) additional fingerprints significantly reduce processing requirements for searching large databases; 3) four or more dab/flat prints of an individual should be incorporated into the IDENT system in order to improve the identification accuracy when searching for a match in the 10-print IAFIS database; 4) slap fingerprints are appropriate for use in large-scale identification systems. Use of slaps can improve system performance and reduce processing requirements when searching databases larger than 10 million subjects; and 5) large identification systems should be multimodal, incorporating demographic, facial, and possibly other biometric data. The impact of errors arising from reliance on a single biometric can be largely overcome by incorporating alternative identifiers.

Fingerprint friction ridge features are generally described in a hierarchical order at three different levels [6, 7]:

- Level 1 (ridge flow): Macro details such as pattern type, ridge flow and morphological features are termed as level-1 features. Examples of level-1 features are arch, tented arch, right loop, left loop, double loop, and whorl.
- Level 2 (minutiae points): Galton features are referred to as level-2 features. These features are ridge ending and ridge bifurcation.
- Level 3 (pores and ridge shape, etc.): ANSI/NIST Committee to Define an Extended Fingerprint Feature Set (CDEFFS) has defined micro features such as pores, ridge contours, dots, and incipient ridges as level-3 features.

Automated Fingerprint Identification Systems (AFIS) generally rely only on a subset of Level 1 and Level 2 features (minutiae and core/delta) for matching. On the other hand, latent print examiners frequently take advantage of a much richer set of features naturally occurring in fingerprints [6]. There are differences in minutiae count between the rolled and the plain (flat) prints of all ten fingers because of the different amount of fingerprint area exposed in the rolled and the plain prints. The rolled prints contain more number of minutiae including features on the sides of the finger [8].

Galton's classification was introduced as a means of indexing fingerprints in order to facilitate searching for a particular fingerprint within a collection of many prints and proposed three basic fingerprint classes: the arch, the loop, and the whorl. Henry subdivided the three main classes into more specific subclasses, namely, arch, tented arch, left loop, right loop and whorl. Generally the most important stage in automatic fingerprint identification system (AFIS) is a fingerprint classification because it provides an indexing mechanism and facilities the matching process over the large databases [9].

The study conducted by Mitretek Systems also analyzed the gender differences in fingerprint quality. The conclusions are [2]: 1) female fingerprints are significantly lower quality than male fingerprints; 2) minutiae-based quality metrics have very similar distributions for males and females; and 3) ridge flow and classification quality measures are very clearly worse for females.

An attempt was made to analyze the association between distribution of fingerprint patterns and gender in India. Results showed: 1) frequency of loops was found to be higher in females (52.42%) than in males (47.58%); 2) whorls were more frequent in males (55.78%) as compared to females (44.22%); and 3) 44.61% of arches were present in males and 55.38% in females [10]. However, some professionals are more concerned about whether or not there is a significant gender difference in fingerprint patterns.

In this paper, the following study has been conducted: 1) the frequencies of different fingerprint patterns were investigated in a group of African Americans at the ages of 16- 30 in the United States; 2) an non-parametric analysis based on the *U* test was conducted to study whether or not there is a significant gender difference in fingerprint patterns.

2. The Fingerprint System and the Experimental Method

The ID 500 10-Print Live Scan System [11], a fingerprint system developed by Cross Match Technologies, Inc., was used in this study in the Automated Identification Technology lab at Mississippi Valley State University, USA. The fingerprint system is shown in Figure 1. The Live Scan Management Software (LSMS) 6.5 was installed in the fingerprint system. The system is a fully FBI-compliant scan system with optical sensors. It has a single fixed capture platen and contains no moving parts. The fingerprint image illumination technology is fully computer controlled for optimal image uniformity. The fingerprint image quality score is from 0 to 100. The LSMS automatically checks the fingerprints to ensure the correct fingers are used when taking a set of fingerprints. When selecting the fingerprint *Capture* button, you are prompted to obtain fingerprints with the following sequence: left slap fingers, left slap thumb (actually is the left flat thumb), right slap thumb (actually is the right flat thumb), right slap fingers, rolled right thumb, rolled right index, rolled right middle, rolled right ring, rolled right little, rolled left thumb, rolled left index, rolled left middle, rolled left ring, and rolled left little [11].

The author of this paper captured left slap fingers, left flat thumb, right flat thumb, and right slap fingers to investigate the fingerprint patterns of a person's 10 fingers. The patterns of the left index, the left middle, the left ring, and the left little can be obtained from the image of left slap fingers at the same time. The patterns of the right index, the right middle, the right ring, and the right little can be obtained from the image of right slap fingers at the same time. The image of an individual finger in the slap fingers can be obtained through the slap fingerprint segmentation process.

The fingerprint patterns identified through the Live Scan system are loops (left loops or right loops), whorls, and arches (plain arches or tented arches). The double loop type is often counted as whorl; therefore, all double loops in this paper are counted as whorls. Loops can be either radial or ulnar, depending on which side of the finger the lines enter. Radial loops and ulnar loops will also be investigated in this study.

Figure 1. The ID 500 10-Print Live Scan system

3. Experimental Results and Discussion

3.1. Flat Fingerprint, Rolled Fingerprint and Slap fingerprint

The commonly used fingerprint patterns are loop, arch, and whorl. The distribution of the patterns in nature is not uniform. The ID 500 10-Print Live Scan system can capture flat fingerprints (Figure 2(a)), rolled fingerprints (Figure 2(b)), and slap fingerprints (Figure 3). There are white lines/cracks/worn ridges in Figure 2(b), which indicates dry or rough skin. The fingerprint quality of Figure 2 (b) passed because the quality within the fingerprint pattern area is fair.

(a) flat left thumb (African American, male)

(b) rolled right thumb (Asian, male)

Figure 2. Flat fingerprint and rolled fingerprint

Figure 3. Slap left fingers (Asian, male)

3.2. Fingerprint Patterns

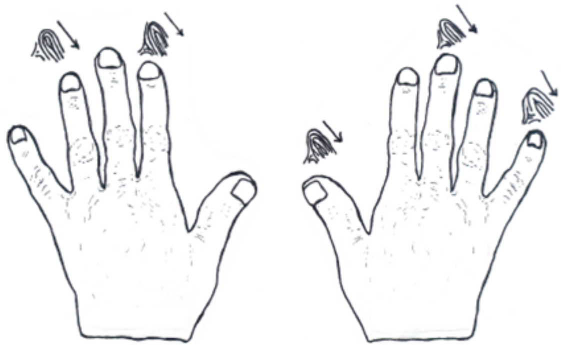
(a) left loop (flat left thumb, Asian, male)

(b) right loop (flat right thumb, Asian, male)

Figure 4. Left loop and right loop

Figure 4 shows the loop pattern (left loop and right loop). A left loop has ridges that enter and leave from the left side; while a right loop has ridges that enter and leave from the right side.

For a loop, if its ridges flow in the direction of the thumb, the loop is called radial loop; if its ridges flow in the direction of the little finger, it is called ulnar loop. The radial loop and the ulnar loop are shown in Figure 5 [12].



(a) radial Loop

(b) ulnar Loop

Figure 5. Radial loop and ulnar loop

The double loop pattern is often counted as whorl. Double loops in this study are counted as whorls. Figure 6 shows a plain whorl and a double loop.

(a) plain whorl (Caucasian, male)

(b) double loop (African American, female)

Figure 6. Whorls

(a) arch (African American, male)

(b) arch with bifurcations on arch ridges (African American, male)

Figure 7. Arches

There are two types of arches: plain arches and tented arches. While the plain arch tends to flow rather easily through the pattern with no significant changes, the tented arch does make a significant change and does not have the same easy flow that the plain arch does [13]. Figure 7 shows plain arches. In Figure 7 (b), there are bifurcations on arch ridges. Figure 7 (a) and Figure 7 (b) were obtained from two people's slap right fingerprints through the slap fingerprint segmentation process. Figure 7 (a) is the right middle fingerprint; Figure 7 (b) is the right index fingerprint.

3.3. Statistical Data for Fingerprint Patterns

In addition to the above subjects tested, 30 African Americans (15 males and 15 females) at the ages of 16- 30 participated in fingerprint experiment in April, 2014. Each participant's 10 fingers were tested and their fingerprints were captured by the ID 500 10-Print Live Scan system. Table 1 shows a breakdown in fingerprint pattern, number, and percentage. It is shown in the table that the loop is the most common of all the patterns while the arch is the least common pattern with a very small percentage (4.33%). Among the 179 loops in Table 1, there are 171 (95.53%) ulnar loops and eight (4.47%) radial loops. Among the 13 arches, there are eight (61.54%) plain arches and five (38.46%) tented arches.

Table 1. Distributions of fingerprint patterns for 30 African Americans

Fingerprint Pattern	Number	Percentage (%)
Loops	179	59.67
Whorls	108	36.00
Arches	13	4.33
Total	300	100.00

Table 2 is a frequency distribution of fingerprint patterns for the males and females of the 30 African Americans. The table shows that African American females have a higher incidence of loops and arches whereas African American males have a higher incidence of whorls.

Table 2. Distribution of fingerprint patterns for the males and females of the 30 African Americans

Fingerprint Pattern	Male	Female
Loops	84 (46.93%)	95 (53.07%)
Whorls	58 (53.70%)	50 (46.30%)
Arches	6 (46.15%)	7 (53.85%)

4. Non-Parametric Analyses for Males and Females

Table 2 shows there is gender difference in fingerprint patterns. However, some professionals are more concerned about whether or not there is a significant gender difference in fingerprint patterns. The author conducted a comparative study in fingerprint patterns between the above African American males and females. The following null hypothesis is formulated:

There is no statistically significant difference in a fingerprint pattern (loop, whorl, or arch) between the males and females.

The outcome is: the hypothesis is accepted or rejected at $\alpha = 0.05$. α is the level of significance.

The author uses *U* test, a non-parametric method, to test the hypothesis. The advantage of non-parametric methods is that no specific assumptions (such as normal distribution) about the population or the sample are required. Therefore, non-parametric methods can be used under more general conditions [14]. Especially, the collected data samples in this study are small samples; a parametric method is not a good choice for small samples. The *U* test is illustrated as follows:

Suppose that W_1 is the sum of the ranks of the values of the first sample (males); W_2 is the sum of the ranks of the values of the second sample (females) n_1 and n_2 are the first sample size and the second sample size, respectively. The statistic U is decided based on the following statistics:

$$U_1 = W_1 - \frac{n_1(n_1+1)}{2} \quad (1)$$

$$U_2 = W_2 - \frac{n_2(n_2+1)}{2} \quad (2)$$

U equals the smaller of the values of U_1 and U_2. The *U* test has the following criterion:

Reject the null hypothesis if $U \leqslant U'_\alpha$, where U'_α is given in Table 3 [14]. $U'_\alpha = 64$ for $n_1 = 15$, $n_2 = 15$, and $\alpha = 0.05$. The *U* test results about the fingerprint patterns (loop, whorl, and arch) are shown in Table 3. Table 3 indicates that all *U* values exceed 64. The null hypothesis cannot be rejected; in other words, there is no significant gender difference in loops, whorls, and arches respectively between American males and females.

Table 3. The *U* test for the fingerprint patterns between African American males and females ($U'_\alpha = 64$)

Fingerprint Pattern	Loops	Whorls	Arches
U_1	91	132	110.5
U_2	121	93	114.5
U	91	93	110.5
Outcome: Significant difference?	No	No	No

5. Conclusions

The fingerprint patterns of a person's 10 fingers can be automatically identified through the ID 500 10-Print Live Scan system. The fingerprint testing on 30 African Americans indicates that the loop pattern (accounts for 59.67%) is the most common, followed by the whorl pattern (36.00%), while the arch is the least common pattern with a very small percentage (4.33%). 95.53% loops are ulnar loops while only 4.47% loops are radial loops. Among the small percentage of arches, plain arches account for 61.54% and tented arches account for 38.46%.

The frequency distribution analysis shows that there is gender difference in African American fingerprint patterns (loop, whorl, and arch); however, the results obtained from the non-parametric method based on the *U* test indicate that there is no significant difference between African American males and females if the level of significance α is 0.05.

For the authors' future work, an increased number of more racially diverse people will be examined for fingerprint difference and other examinations.

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