Fingers and Toes: A Hidden BioMetric Story

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***Abstract*— The work presented in this paper has two main objectives. The first objective was to determine if fully related siblings have similar fingerprints due to genetics. The data showed that only one sibling set had less than 40% similarity. The right index finger of all sets had a median of 40%, even within one set of siblings that had only a 20% match on the right thumb. The mode for the left index fingers was 40% with twelve of the fifteen sibling sets being at that level. The majority of the sets were at 33% or higher, yet two sets had no matching major classifications and the mode for ridge classifications was 80%. Arches were the least found major classification and loops were the most popular major classification. The hypothesis was that fully related siblings would have similar fingerprints. The results support the hypothesis even though the fingerprints may have slight differences within some classifications, all sibling sets having at least an 80% similarity. The second objective was to determine if fully related siblings have similar toeprints. The data from toeprint collections showed that most of the sibling sets ridge classifications being 80% similar and three of them 90% similar. While the similarity of the ridge classifications did not vary much, the similarity of the major classifications varied.**

Keywords- Fingerprints; Toeprints; Biometrics; Security; Science.

I. Introduction

Fingerprints are a biometric mark of everything a human has touched and where they have been. Fingerprint tracking has been documented from the Chinese Qin Dynasty to modern society. There currently is no common fingerprint point requirement between countries, but the more point matches, the stronger the match. Fingerprints have basic patterns and more detailed patterns that allow for good evidence of a match. Just as fingerprints are unique to a person, so are toeprints. There are three basic patterns of fingerprints known as arches, loops, and whorls [5]. The more detailed items of fingerprints are forks, double forks, triple forks, delta, dot, bridge, hook, eye, short ridge, and ending ridge [8]. It can be inferred that toeprints are classified using the same classifications as fingerprints because they have similar characteristics [3]. Trying to classify toeprints and footprints to identify crime victims and to help catch criminals is not new. Moorthy and Sulaiman [18] attempted to help solve crime in Malaysia by collecting footprints of over 400 adults and found various features of the toes. When they compared them against findings of those in Indians, they found that the morphological length of toes were different due to nationality and genetic makeup [18].

In Section 2, a brief history of fingerprints and toeprints and background for understanding fingerprints and toeprints is given. In Section 3, the data for the fingerprint and toeprint research is presented and explained. In Section 4, a summary of research and possibilities of future research are given.

II. History

Before Christ (BC) the Chinese Qin Dynasty recorded details of using handprints as a way to find burglars and Han Dynasty records show clay seals showing fingerprint ridge impressions [24]. Von Minden also indicates evidence of fingerprinting in the 14th century Persian book *Jaamehol-Tawarikh* by Khajeh Rashiduddin Fazlollah Hamadani, that there is evidence of the Dr. Nehemiah Grew publishing details of friction ridge skin observations in the *Royal Society of London* paper in 1684, Govard Bidloo writing a book in 1685 about papillary ridges, and Marcello Malpighi at the University of Bologna's work with ridge, spirals, and loops in 1686 [24]. French criminologist Alphonse Bertillon created an eleven point measurement system known as anthropometrics [11]. The anthropometry system failed when two people were found to have the same eleven measurements in the Will and William West Leavenworth Prison case [11]. This sparked several scientists to start looking for improved ways to identify people by their fingerprints. The following timeline shows the movement from the judicial failure of anthropometrics to modern fingerprinting [9][11]-[13][23]-[24]:

- 1893-Scotland Yard adds fingerprints to Bertillon
- 1901-Fingerprints replace anthropometrics ID
- 1902-New York, USA fingerprints used for work ID
- 1905-U.S. Military starts using fingerprints
- 1918- Locard confirmed 12 point differences
- 1971-Federal Bureau of Investigation (FBI) has over 200 million fingerprints stored
- 1974-United Kingdom created a fingerprint society
- 1977-Certified Latent Print Examiners test created
- 2012-Interpol's repository includes 190 countries
- 2014-U.S. Automated Fingerprint Identification System (AFIS) systems has over 120 million fingerprint records
- 2014-Unique Identification Authority of India (UIAI) has over 560 million biometrics stored

The classification system that is used today evolved from a method developed by Sir Edward Henry who was in collaboration with Sir Francis Galton, Sir William Hershel, and Dr. Henry Faulds [11].

Fingerprints contain DNA and substances that are on the finger. Recently, researchers have been working on the best way to obtain and analyze DNA from latent fingerprints with the goal of provide another source of gathering DNA samples for criminal investigations [6]. Also, other researchers are looking at the traces of non-DNA substances left in fingerprints to find more information that may be used in criminal investigations [1]. Most of the research on non-DNA substances in fingerprints is focused on drug testing [1].

In history, toeprints have served a significant purpose. There was an article in the *Fingerprint and Identification Magazine* from March 1953 titled The Case of the Great Toe Print. The police found a toeprint on a safe that was stolen during a robbery and the guilty verdict was based on the toeprint alone [21]. In 2010, police identified Colton Harris-Moore as the barefoot bandit through his toeprints [20]. Additionally, another example would be when coroners in Japan decided to use footprints to identify the deceased of an earthquake [2]. Beall also reported that this method could be used to identify patients with dementia [2]. Despite the advantages of using toeprints for identification purposes, it should be noted that a ghost image or shadow may appear two-dimensional within latent prints [4]. This phenomenon has implications for the collection and interpretation and thus for the comparison made between unknown and known footprints in the criminal justice system [4].

A. Patterns

Fingerprints have several characteristics which are categorized into two main categories. The first category focuses on basic patterns and the second category focuses on the more detailed items within the basic patterns. There are three basic patterns known as (1) arches, (2) loops, and (3) whorls. Arches are the least common of the basic patterns [5]. The pattern of an arch can be identified because the ridges enter on one side and exit on the other side. About 5% of people have arch type fingerprints [17]. Loops are the most common type of print [5] and in this pattern some of the ridges enter and exit on the same side of the finger. “Approximately 65% of all fingerprints are loops” [17]. Whorls are the third pattern and these ridges create a circular pattern. According to the Education Bureau of Hong Kong, approximately 34% of people exhibit this as their basic fingerprint pattern [8].

The more detailed items are forks, double forks, triple forks, delta, dot, bridge, hook, eye, short ridge, and ending ridge [8]. As explained by the Education Bureau of Hong Kong, a fork is similar to when one is driving and comes to a dead end in the road that forces one to make a decision about going left or right [8]. A double fork is when the fingerprint line branches off to the left or right and then immediately makes another left or right branch. A triple fork is when someone’s fingerprint comes to the intersection, but instead of just turning right or left, the line can also go straight [8]. The delta is also known as bifurcation and sometimes people have two deltas which is known as a double bifurcation [5]. A dot characteristic allows a person to have a single dot or multiple dots anywhere in their fingerprint [8]. A small ridge connecting two large ridges is known as a fingerprint bridge. Spurs known as hooks, look like a crochet hook and the hook varies in different depths [5]. An eye is also known as an enclosure or a lake and is basically the same as an eyeball. Short ridges are also known as islands, because the ridge lines are small and do not connect to any other ridge [5]. The last detail is the ending ridge, which is where the print ridge lines end and do not make a full ridge [8]. The same fingerprint patterns also apply to toeprints.

B. Types

The four types of fingerprinting methods are plastic, visible, latent, and inked. According to Gaensslen et al. [11], plastic fingerprints are generally “three-dimensional and found in soft material”, while visible fingerprints are generally left in fluids, such as paint or blood, and latent fingerprints are invisible to the human eye, but are made visible by dusting or spraying chemicals on the print. Ink fingerprints are the older style, where fingers are rolled in ink and printed on a paper card. An example of a plastic fingerprint would be your print left in putty and an example of a visible fingerprint would be when you stick your hand on wet paint and leave your hand print on the wall. Another example of a visible fingerprint is when someone puts their hand on a non-fogged window, the next morning fog shows the persons handprint.

There are two primary ways to obtain latent prints: (1) powered-dusting and (2) chemical spray [11]. The multi-colored powders are cheaper and commonly used in conjunction with lifting tape and specially designed brushes. The most common chemicals used are iodine fuming, silver nitrate, ninhydrin, and super glue [11]. Lipid components and porous surfaces respond well to using iodine, while ninhydrin reacts with amino acids and also works well on porous surfaces [11]. “Silver nitrate has been an established agent for the detection of latent fingerprints for some 120 years, and it was one of the few reagents suitable for use on porous surfaces until ninhydrin was introduced in forensics. The method is based on the reaction of silver ions with chlorides in the fingerprints, which are visualized in brown, violet or black” [15]. By heating the super glue, an interaction occurs on the print residue displaying a visible fingerprint impression [11]. The same fingerprint types also apply to toeprints.

C. Analyzing

One way to compare and analyze fingerprints is to follow the five steps below [8]:

1. Identify the basic patterns (loop, arch, whorls) of a fingerprint
2. Identify ridgeline details
3. Compare fingerprint measurements point by point to another fingerprint
4. Determine if capture print matches prior stored print

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5. Obtain second person or software program to confirm findings

Using a computer software program to analyze fingerprints is much faster and easier as manual fingerprint comparison generally requires the use of a magnifying glass. During the comparison, the examiner must record their findings, generally in a digital database that can be searched later. These stored analyses are helpful in biometric security, identifying amnesia victims, criminal identification, and identifying unknown deceased [19]. As the USA National Forensic Science Technology Center and Bureau of Justice Assistance points out, most criminal justice cases use computerized systems to conduct the analysis for matches. The match is determined by a programed algorithm. Certified print examiners then manually review the listed matches and make the final determination [19]. “Fingerprint examiners use a method called ACE-V. That stands for analysis, comparison, evaluation, and verification. Below is an explanation of each section of ACE-V” [19].

Analysis is the process of determining if the print is good enough to use for a comparison. If the print is found not to be suitable for comparison, it is because it was not of good quality or did not have enough visual features; at this point, the print is reported as not suitable. If the print passes inspection, the print tolerance level (the amount of variation that will be accepted) is determined [19]. “The analysis may also uncover physical features such as recurves, deltas, creases, and scars that help indicate where to begin the comparison” [19]. Comparisons occur when prints from known persons and people of interest are looked at side-by-side comparing minutiae characteristics and locations to determine if they match. “Known prints are often collected from persons of interest, victims, others present at the scene or through a search of one or more fingerprint databases such as the FBI’s Integrated Automated Fingerprint Identification System” [19]. “Evaluation is where the examiner ultimately decides if the prints are from the same source (identification or individualization), different sources (exclusion) or is inconclusive. Inconclusive results may be due to poor quality samples, lack of comparable areas, or insufficient number of corresponding or dissimilar features to be certain” [19]. Verification is when someone else does the analysis, compares, and evaluates the prints themselves to either support or disagree with the conclusions of the first fingerprint examiner. The second examiner might additionally verify the suitability of determinations made by the first examiner in the analysis phase [19].

According to the USA National Forensic Science Technology Center and Bureau of Justice Assistance, there are four possible results of fingerprint analysis. These results are “(1) the fingerprint was made by (identified) a known source (suspect, victim, etc.), (2) the fingerprint was not made by a known source, (3) the fingerprint cannot be identified or excluded to a known source, (4) the fingerprint is of no value to compare to a known source” [19].

D. *Measurements*

Fingerprints are measured by points. A system has been created that uses different spots on the fingerprint to compare the similarities. The different spots are called points. There are approximately fifty points per fingerprint. The minimum requirement is different for every country. The United States has no minimum requirement of points that you must have to match a print, however the more you have the better in a court of law. The United Kingdom requires that you to have a minimum of sixteen points to be a match [10]. Australia requires you to have at least a minimum of twelve points to be a match [10]. Just like Australia, Germany requires a minimum of twelve points for it to be a match [7]. France requires you to have a minimum of seventeen points for it to be a match [7]. The US court system and the government does not require you to have a certain amount to have a case, but they prefer that you have at least a minimum of nine points that are a match. At the time of this research, there are no requirements for toes, unless used as finger replacements.

E. *Heredity*

A person’s fingerprints are formed approximately during the seventh month of fetus development, and the finger ridges do not change unless a person gets a bruise, cut, or scar on the fingertip [14]. According to Bhangu [3], the pressure on the toes from the amniotic fluid and the fetus’ movement in the womb affects the resulting toeprints at birth. There are prior studies that show a correlation of ridge count, width, separation, and depth among identical twins, while others show that some parent fingerprint traits are shared with their children [14]. While fingerprinting children under the age of two can be difficult, research has shown there are similarities between family members [22]. “There is an inheritable quality to fingerprints. Pattern types are often genetically inherited, but the individual details that make a fingerprint unique are not” [16].

III. RESEARCH

A. *Fingerprint Analysis*

For this part of the research, there were fifteen sibling sets, or thirty participants, who were fingerprinted. The participants’ fingerprints were analyzed for the major classifications and five specific ridge classifications. Then, fingerprints of siblings were compared and similarities determined.

The data for this part of the research showed that when comparing all three of the major classes and the five ridge classes on the four fingers tested, all the sibling sets had at least 80% similarity, as seen in Figure 1.

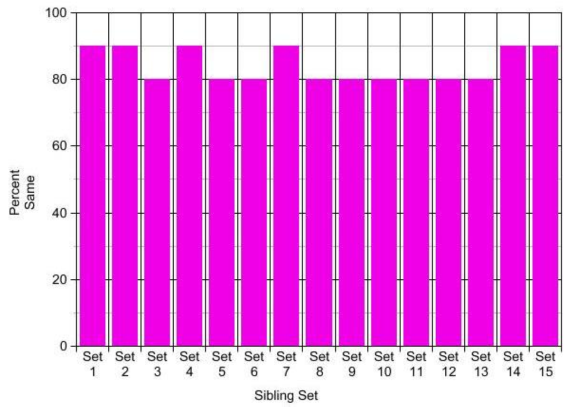

Figure 1. Overall Similarity of Fully Related Siblings Fingerprints

The majority of siblings had at least 33% similarity in the major classes, as seen in Figure 2.

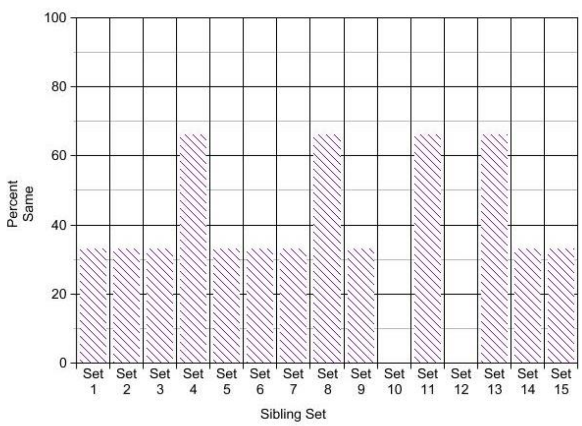

Figure 2. Major Classification Similarity of Fully Related Siblings Fingerprints

Also, the data showed that the right index finger of all sets had a median of 40%, even with Set 7 that had only a 20% match. The right thumb of all sets had a median of 60%, even with Set 8 that had only a 20% match. The left thumb for all sets had a mode of 40%, even with five sets having a 20% match and one set having no similarity in the left thumb. The left index finger for all sets had a mode of 40% with ten of the fifteen sibling sets being at that level.

The individual finger similarities were calculated by taking all found major and ridge classifications and dividing them by all eight possible classifications. The overall percentage of similarity was determined by adding all found matched classifications divided by all possible classifications for all fingers. Major class similarities were further evaluated by looking for similarities of whorls, arches, and loops on matching fingers. The majority of the sets were at 33% or higher, yet two sets had no matching major classifications. This percentage was determined by taking the number of found matches divided by the total possible classifications. When looking at total ridge similarities, the mode was 80%.

The data showed the left thumb was less of a match then the right thumb of siblings. The same was shown to be true on the right and left index fingers. When looking at individual classifications the data showed five sets did not have forks, four sets had double forks, and only one set had a triple fork. There were ten sets that did not have matching short ridges and fourteen sets did not have matching ending ridges. The matches were determined by each sibling within a set having the classification, most sets had at least one sibling who had some type of ridge. Arches were the least found major classification and loops were the most popular major classification. One set of siblings was compared to another because that set consisted of a male parent and a male uncle. The findings were supportive of the prior research showing genetic effects on fingerprints, in that there was an 85% similarity with the parent and a 70% similarity with the uncle. Two sets of siblings also had one female grandparent within another sibling set. When the sibling sets were compared with their grandparent's prints, they found to have a 74% match.

Upon evaluating the quality of the fingerprint cards, it could be seen that the sibling sets that included participants between the ages of two and five years were not as clear which made it harder to determine classification. The participants over the age of 45 also presented issues because they contained more fingerprint damage, such as scars and burn spots. One sibling set had a participant that had a fresh cut which caused a thick solid line to appear across the fingerprint. The younger participant's prints were darker due to the struggle between researcher and participant to roll the finger properly in ink and on the card. The older participants were found to have the lightest prints most likely from the researcher being more concerned about hurting them during the fingerprinting process in comparison to other participants.

B. *Toeprint Analysis*

Confounding variables in this portion of the research were

- Cuts, scrapes, and/or callus on toes
- Lotions and/or oils used on feet prior to printing
- Flexibility of research participants
- Length of participant's toes
- Medical conditions of participants

For this part of the research, there were ten sibling sets, or twenty participants, who were toeprinted. The participants' toeprints were analyzed for the major classifications and five specific ridge classifications. Then, toeprints of siblings were compared and similarities determined.

The average ridge classification similarity was 83%. The average right big toe similarity was 88%. The average left big toe similarity was 78%. The right big toe similarity is the number of ridge classifications similar on the siblings right big toe. The left big toe similarity is the number of ridge classifications similar on the siblings left big toes. The average major classification similarity was 55%.

One set of siblings was compared to another because that set consisted of a female parent and a female aunt. While the researcher was unable to find prior research on the genetic effect of toeprints, the data of this research shows that genetics do play a role in toeprint formation. This is similar to the findings of prior research showing genetic effects on fingerprints [16]. This research showed that there was an 85% similarity with the parent and a 70% similarity with the aunt. Two sets of siblings also had one female grandparent within another sibling set. When the sibling sets were compared with their grandparent's prints, there was a 74% match.

The similarity of ridge classifications, major classifications, the right big toe, and the left big toe in related siblings is graphed in Figure 3.

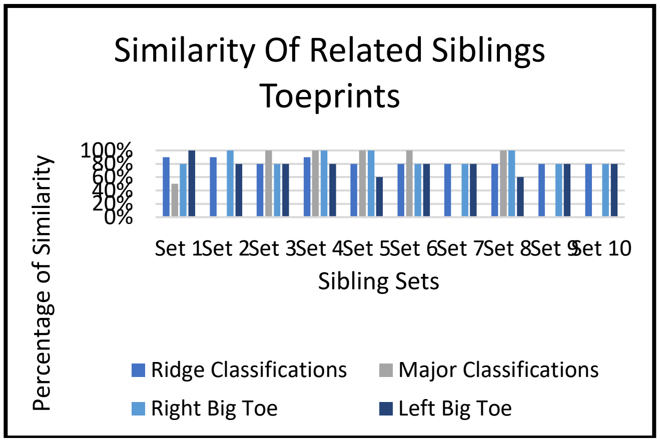

Figure 3. Similarity of Related Siblings Toeprints of Different Ages and Ethnic Backgrounds

IV. Conclusion

Based on the findings of this research, the hypothesis that fingerprints of siblings are similar overall even though they may have slight differences within some classifications with all sibling sets having at least an 80% match. This supports the prior research findings from Jain et al. [14] which states that while everyone has a unique fingerprint, siblings do have similarities based on genetics during fetus development. One set of siblings had a participant who was conceived using in-vitro fertilization and one who was not. The fingerprint results may have shown different results if all five fingers were evaluated instead of just the thumbs and index fingers. This was not done due to time restrictions placed on the researcher by the project due date and when the research received Institutional Review Board (IRB) approval. The researcher also learned how hard it was to actually find full siblings; it appeared that a large majority of siblings around the researcher were actually step or half siblings. It was interesting to the researcher to also see the high interest level of the participants to understand more about fingerprints and the reading process. The researcher now understands why the criminal justice system is unable to set a specific number of matches to confirm a print obtained during a crime. Future fingerprint research is to evaluate all five fingers on each hand for each sibling, to use a digital inking device, and to allow more time for evaluation, fingerprinting all the parents of the siblings, and looking at other biometric prints such as the ear. This additional data may lead to more details of the human biometric system.

The data from the toeprint portion of this research showed that when comparing the three major classes that five sibling sets had a 100% similarity and four sibling sets had absolutely no similarity. Three sibling sets had an overall ridge classification similarity of 90%, which was 10% higher than all other sibling sets. There was no correlation between major class similarity level and the ridge classification similarity level. All sibling sets had at least an 80% or higher similarity for ridge classification on the right big toe. This varied from the left big toe ridge classification comparison, which showed two sibling sets had only a 60% match. Additionally, only one 100% match was found on the left big toe, but four 100% matches were found on the right big toe. The most common percentage was 80% for both the right and left big toes. Major class similarities were further evaluated by looking for similarities of whorls, arches, and loops on matching toes. Half of the sets were at or below 50% and the other half were perfectly matched at 100%. This percentage was determined by taking the number of found matches divided by the total possible classifications. When looking at total ridge classification similarities, the mode was 80%. The data showed the left toe was less of a match than the right toe of siblings. When looking at individual ridge classifications the data showed that both participants in the set had forks, seven sets had double forks, and no set had a triple fork. All ten sets had ending ridges and only two sets had both participants having short ridges. The matches were determined by each sibling within a set having the classification; most sets had at least one sibling who had some type of ridge. Whorls were the least found major classification and loops were the most popular major classification.

Comparing the manual and computer analysis there is a slight to major difference. The cause of the difference is that manual analysis considered only certain classifications (three major and five ridge classifications) and the computer looked at all possible major and ridge classifications for fingerprints. The five ridge details in the manual analysis were forks, double forks, triple forks, short ridge, and ending ridge. The ridge details looked at in the computer analysis are fork, double fork, triple fork, delta, dot, bifurcation, double bifurcation, opposed bifurcation, lake, short ridge, and ending ridge. Upon evaluating the quality of the toeprint cards, it could be seen that the sibling sets that included participants under the age of twelve were not as clear, which made it harder to determine classification. The participants over the age of 45 also presented issues because they contained more toeprint damage, such as scars and calluses. Younger participant's prints were darker and older participant's prints were lighter.

In conclusion, the toeprint findings show that the hypothesis that toeprints of siblings are similar overall even though they may have slight differences within some classifications with all sibling sets having at least an 80%

match in the ridge classifications. This supports the prior research findings for fingerprints done by Langenburg [16], which stated that while everyone has a unique print, siblings do have similarities based on genetics and differences from fetus development. Future research in the area of toeprints include creating a toeprint database and looking at toeprints as an indicator of medical conditions.

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