جامعة نايف العربية للعلوم الأمنية
NAIF ARAB UNIVERSITY FOR SECURITY SCIENCES
Est. 1978

Naif Arab University for Security Sciences
Arab Journal of Forensic Sciences and Forensic Medicine
المجلة العربية لعلوم الأدلة الجنائية والطب الشرعي
https://journals.nauss.edu.sa/index.php/AJFSFM

الجمعية العربية لعلوم الأدلة الجنائية والطب الشرعي
Arab Society for Forensic Sciences and Forensic Medicine

Demographic Variability in Fingerprint Patterns

التباين الديموغرافي في أنماط بصمات الأصابع

CrossMark

Amna Arooj[1]*; Hafiz Muhammad Abbas Malik[2]; Faizan Akram[2]; Hifz Ur Rehman[3]; Kashaf Tul Wuda[1]

[1] Department of Forensic Science, Faculty of Allied Health Sciences, The Islamia University of Bahawalpur, Bahawalpur, Pakistan

[2] Department of Pharmaceuticals, Faculty of Pharmacy, Islamia University of Bahawalpur, Bahawalpur, Pakistan

[3] Institute of Biological Sciences, Khwaja Fareed University of Engineering and Information Technology, Rahim Yar Khan, Pakistan

Received 19 Mar. 2025; accepted 16 Jun. 2025; available online 24 Jun. 2025.

Abstract

Fingerprints' unique patterns are the source of human identification, particularly for forensic investigations. Several studies established an association of fingerprint patterns with demographic variables like age, gender, blood group, and social behavior, but these relations lack statistical evidence. Additionally, a socio-demographic factor, caste, remains unexplored. Here, we report the statistical relationship of demographic factors with fingerprint patterns in Bahawalpur, Pakistan. A quantitative and qualitative approach is utilized to study fingerprint patterns of 500 female individuals. Loop pattern accounts for 64.5%, followed by whorls 27.4% and arches 8.1%, in the sampled population. Among all castes, the loop pattern dominates, followed by whorls and arches. Rajpoot and Malik have slightly higher portions of whorls compared to other castes. A 1-sample t-test shows the variability among demographic factors and indicates that the fingerprint pattern may have some influence on demographic factors. One-way ANOVA highlights that caste may have some significant relation with arches and whorls, while age and blood group show no statistical significance. Pearson correlation and Spearmen Rank's correlation test give a significant p-value of 0.008 and 0.019, respectively, for caste and fingerprint patterns and support that a significant relationship exists, although weak. These findings emphasize the stability and reliability of fingerprint patterns as biometric identifiers in forensic investigations, especially in a particular demographic region.

Keywords: Forensic sciences, age, blood group, caste, race, fingerprint patterns, socio-demographic factor.

المستخلص

تُعد الأنماط الفريدة لبصمات الأصابع مصدرًا لتحديد هوية الإنسان، لا سيما في تحقيقات الطب الشرعي. لقد أثبتت العديد من الدراسات وجود ارتباط بين أنماط بصمات الأصابع والمتغيرات الديموغرافية مثل العمر والجنس وفصيلة الدم والسلوك الاجتماعي، لكن هذه العلاقات تفتقر إلى الأدلة الإحصائية. بالإضافة إلى ذلك، يظل عامل اجتماعي ديموغرافي، وهو الطبقة الاجتماعية، غير مستكشف. في هذا البحث، نقدم العلاقة الإحصائية للعوامل الديموغرافية بأنماط بصمات الأصابع في بهاولبور، باكستان. تم استخدام منهج كمي ونوعي لدراسة أنماط بصمات الأصابع لـ 500 فرد من الإناث. يمثل نمط العروة 64.5% (pooL) ، يليه النمط الدائري (Whorl) بنسبة 27.4%، ثم النمط المقوس (Arch) بنسبة 8.1% في العينة السكانية. بين جميع الطبقات الاجتماعية، يهيمن نمط العروة، يليه النمط الدائري والنمط المقوس. يمتلك الراجوبت والمالك نسبًا أعلى قليلاً من الأنماط الدائرية مقارنة بالطبقات الأخرى. يُظهر اختبار t لعينة واحدة التباين بين العوامل الديموغرافية ويشير إلى أن نمط بصمة الإصبع قد يكون له بعض التأثير على العوامل الديموغرافية. يسلط تحليل التباين أحادي الاتجاه (ANOVA) الضوء على أن الطبقة الاجتماعية قد يكون لها علاقة مهمة بالأنماط المقوسة والدائرية، بينما لا يُظهر العمر وفصيلة الدم أي أهمية إحصائية. يعطي اختبار بيرسون للارتباط واختبار سبيرمان للرتب قيمة احتمالية مهمة تبلغ 0.008 و 0.019 على التوالي، للطبقة الاجتماعية وأنماط بصمات الأصابع، ويدعمان وجود علاقة مهمة، وإن كانت ضعيفة. تؤكد هذه النتائج على استقرار وموثوقية

الكلمات المفتاحية: علوم الأدلة الجنائية، العمر، فصيلة الدم، الطبقة الاجتماعية، العرق، أنماط بصمات الأصابع، العامل الاجتماعي الديموغرافي.

Production and hosting by NAUSS

* Corresponding Author: Amna Arooj
Email: amna.arooj6666@gmail.com

doi: 10.26735/AKLW5588

Future research should implement these findings in a larger population sample and demographic region to understand fingerprint patterns variability further.

أنماط بصمات الأصابع كمعرفات بيومترية في تحقيقات الطب الشرعي، خاصة في منطقة ديموغرافية معينة. يجب أن تطبق الأبحاث المستقبلية هذه النتائج في عينة سكانية ومنطقة ديموغرافية أكبر لفهم تقلب أنماط بصمات الأصابع بشكل أكبر.

1. Introduction

The ridges on the median side of the fingers of human hands exist in a pattern that varies in every individual. These unique patterns are known as fingerprints. Dr. Nehemiah Grew was the first European to publish friction ridge skin observations. He described the ridges, furrows and pores of both the human hands and feet [1]. German anatomist Johann Christoph Andreas Mayer, in his book Anatomical Copper-plates with Appropriate Explanations, was the first person to declare friction ridge skin is unique to each individual [2]. For identification purposes, Sir William Herschel used fingerprints for the first time during the 1850s [3]. Sir Francis Galton studied fingerprints scientifically and made them to be used in legal matters [4]. Fingerprints are highly individualistic, even between two fingers of the same hand and in the hands of identical twins, due to the complex pattern of epidermal ridges that remain the same throughout one's life [5].

Unlike DNA Profiling and facial recognition, fingerprint analysis offers a cost-effective, non-invasive, and rapid method of identification as it links the individual to the scene of crime with high certainty [6]. Automated Fingerprint Identification System (AFIS) further transformed the process by allowing the comparison of fingerprints against databases, ultimately boosting the reliability and utility of fingerprints in legal procedures [7].

Despite the universality and reliability of fingerprint analysis, there is a prominent gap in knowledge to comprehend the extent to which demographic variables contribute to fingerprint patterns. Therefore, comprehensive research is carried out among females belonging to different age groups and castes in Bahawalpur to answer how demographic variables like age, gender, blood group, and caste impact fingerprint patterns, and these variables should be considered in forensic investigations.

This research study aims to explore the demographic variability in fingerprint patterns and evaluate its findings for forensic science. By thoroughly analyzing the relationships among demographic variables and fingerprint patterns, this study proposes to provide new insights that could improve identification methods and potentially influence forensic protocols.

Fingerprint patterns' demographic variables have the potential to present significant advancements in forensic science. The influence of several variables on fingerprint patterns has been noted in some studies but remains insufficiently explored. For example, research shows that ridge density differs among genders, such as women tend to have a higher ridge density than men [8]. Another study tries to find the relationship between blood group, gender, and fingerprint pattern [9]. Similarly, aging may affect ridge density, potentially impacting the interpretation between age groups and genders [10].

Integrating demographic characteristics into fingerprint examination could lead to a stronger profiling method. For instance, if certain fingerprint features are found to relate to specific characteristics, forensic experts could use this information as evidence during investigations. Such incorporation would increase the precision and circumstantial relevance of fingerprint databases by accounting for variability in diverse populations [11].

Also, this demographic-focused research may contribute to the reduction of biases in forensic science. By identifying and classifying demographic differences, forensic databases can better characterize a range of populations, leading to more equitable results in criminal justice [12]. The results could be helpful for forensic examiners, ensuring that factors influencing fingerprint patterns variability are considered during analysis.

Due to the reliability and unique nature of epidermal ridges, fingerprint analysis is one of the most widely used techniques in forensic science. Fingerprint formation takes place in the embryo during the 10th – 16th week [13]. During the 10th week, embryonal volar skin comprises the layered epidermis (consisting of the periderm, intermediate layer, and basal layer) above the more amorphous fibrous dermis [14-18]. In the 11th week, the basal layer is composed of columnar cells whose axis is perpendicular to the surface of the skin. The basal becomes prominent after becoming undulated and then forms folds of the epidermis into the dermis. These folds are called primary ridges, which become more prominent by the 16th week [14 & 19].

The pattern of fingerprints is classified into three types such as arches, loops, and whorl. Loops, among 60-65% of the population, are those ridges that enter from one side, curve around, and exit on the same side. The ulnar loop enters from the little finger side, while the radial loop enters from the thumb side. Arches, least among the population, about 5%, are ridges that enter from one side, rise a bit, and down to exit from the other side, forming a wave-like pattern. Tented arches form a sharp wave rise relative to normal arches. Whorl, among 30-35% of the population, are ridges that exist in spiral or circular patterns. Whorl patterns are most diversified such as Plain whorls contain concentric circles, the Central Pocket Loop has a loop with a whorl at the end, the Double Loop makes an S-like pattern, and the Accidental Whorl has an irregular ridge pattern [20-23].

Several research studies have investigated the relationship between fingerprint patterns and various factors associated with humans. Gender differences were explored in the fingerprint pattern distribution and it was found that females display a higher frequency of loops and arches, while whorls are more common in males [24]. Another study declares no relation between fingerprint pattern and blood group but established a connection of ridge pattern with social behavior [25].

The hereditary traits theory in biometric studies emphasizes that genetic makeup influences physical characteristics, including fingerprints. In the fetus, fingerprints start to develop from the 10th week and are completely formed by approximately the 16th week of gestation, and are impacted by both genetic as well as environmental factors like amniotic fluid, intrauterine pressure, and maternal health [26]. Genetics can influence fingerprint formation, such as the mutation in a gene, SMARCAD1, which is responsible for the absence of fingerprints causing adermatoglyphia or immigration delay disease [27].

Genetic influence is apparent in studies that show a resemblance in fingertip patterns among family members [28]. Slatis et al. (1976) give a theoretical explanation regarding the inheritance of fingerprint patterns, saying that there are dominant and recessive genes for a particular pattern on a particular finger [29]. This dual influence supports the hypothesis that demographic aspects often relate to genetic lineage and population-specific traits, which might affect fingerprint patterns.

Despite a strong foundation in biometric research, integrating hereditary and social characteristics like caste or race into fingerprint patterns studies is rare. The idea that caste-specific genetic features could manifest in ridge patterns aligns with comprehensive theories of human diversity in biometric characteristics. However, empirical data is limited, and studies often flop to isolate caste or race as a variable different from other socio-demographic factors [30-31].

The most obvious space in current literature is the lack of meticulous analysis of caste and its potential relationship with fingerprint patterns. Most studies have focused on other demographic factors, but the trends among castes remain unexplored. This presents a significant opportunity for further research, especially in regions with caste systems that could influence genetic diversity. This gap is surprising as these systems often involve endogamy, which conserves genetic traits in generations.

Sociopolitical sensitivity around caste-based could be the reason for this research gap. However, discovering these relations could give more insights into forensic practice in regions like Pakistan, where caste is a major social factor. Also, the deficiency of a comprehensive dataset, including age, blood group, and caste, limits the ability to perform large-scale analysis. This provides an opportunity to explore demographic factors associated with fingerprint patterns, contributing to an in-depth understanding of these factors in forensic science.

2. Method

2.1. Research Design

This study was about the impact of demographic variables on fingerprint patterns and was correlational research. It employed a mixed-methods design combining both qualitative and quantitative approaches. This ensured complete data analysis, allowing statistical evaluation and providing relative insights into findings. Furthermore, a cross-sectional approach is implemented to the region of Bahawalpur. The primary data was collected and used to draw results and conclusions. The data from the selected population was collected by interviewing and sampling fingerprints [32-34]. Stratified random sampling ensured that each subgroup (caste, age, blood group) was proportionally represented. This decreased sampling bias and ensures diversity within the dataset, making the analysis more concrete.

2.2. Data Collection Method

The population size was set to 500 female individuals selected randomly in Bahawalpur. The samples were collected from different locations such as Islamia University's Forensic Science Department (80 samples), Department of Physiotherapy (50 samples), Medical Laboratory Technology Department (20 samples), Department of Homeopathic Medicine and Surgery (30 samples), Pharmacy Department (35 samples), Physical Education Department (18 samples), Physics Department (23 samples), Information Technology Department (17 samples), Bioinformatics Department (25 samples), Quaid e Azam Medical College (10 samples), Bashir Town (25 samples), Shadaab Colony (20 samples), Sajid Awan town (40 samples), Model Town A (47 samples), and Reads Law College (60 samples).

The notices regarding the call for research participants were placed on notice boards at each location and a research camp was established at each location, where each camp was attended by two individuals. The surroundings were maintained well-lit and ventilated. First, all the participants were informed about the research aims, methods, and data privacy protocols. Each participant was interviewed separately, in which they were questioned about their age, blood group, caste, and other personal information. Written informed consent was obtained, from each participant to comply with ethical standards. Participants were guided on how to give fingerprints on the ten-print card (usually preferred by the Crime Scene Unit, Bahawalpur). Participants' Fingers were cleaned using Dettol wet tissues. A standard black ink stamp pad is preferred to get more clear prints. The participants were asked to press their fingers gently, one by one, on a stamp pad and placed in respective places on the ten-print cards. Only plain prints were taken as samples. Again, their fingers were cleaned using Dettol wet tissues.

2.3. Sample Selection

The study drew participants from diverse backgrounds, ensuring representation across different age brackets (e.g., 16-30, 31-45, 46-60), different blood groups (A, B, AB, and O), and different caste classifications reflective of local demographic composition. The sample size of 500 participants possessed distribution across the strata and enables significant statistical analysis. This sample size had balanced logistical feasibility with the need for reliable and generalizable results.

Sample Inclusion standards were based on participants who gave informed consent to the study and had unaltered and clear ridge patterns. Sample exclusion standards were based on participants with scars, cuts, amputation, and unreadable fingerprint patterns. Samples from individuals with henna over the fingers were also excluded because this impacted fingerprint pattern clarity.

2.4. Data Analysis Technique

The fingerprint patterns collected from participants were examined and categorized based on standard pattern-type classification, focusing on the three fundamental fingerprint pattern groups (arches, loops, and whorls). This classification was conducted by trained individuals with experience in fingerprint analysis under the supervision of a forensic science faculty member. Each fingerprint was visually inspected for ridge flow, delta points, and core characteristics to determine the appropriate pattern group. Although this approach is inspired by foundational aspects of the Henry Classification System, it does not extend to the full numerical classification scheme originally developed for law enforcement indexing. Instead, the classification aimed to identify general pattern trends. Once classified, the fingerprint data were grouped according to the caste affiliation of each participant as recorded during demographic data collection. This grouping enabled comparative analysis of fingerprint pattern distributions across caste lines, allowing for the exploration of any demographic or hereditary influences on dermatoglyphic traits.

Statistical analysis was applied to samples under inclusion criteria. T-test, Analysis of Variance (ANOVA), and Correlation analysis were used to find the significance of demographic variables with fingerprint patterns. The 1-sample t-test compares the mean of a single sample to a known value or a hypothesized population. This indicates whether the average measurement of a particular variable differs significantly from the specific value. This test assessed whether the mean occurrence of a specific fingerprint pattern in a sample group is different from the mean of the population sample [35]. One-way ANOVA determines whether there are significant differences between three or more independent (unrelated) groups. This was used to compare the mean number of fingerprint patterns across demographic factors [36]. The Correlation test measures the extent to which two variables are linearly related [37]. Pearson correlation coefficient measures linear relationships, and Spearmen correlation is used for non-linear relationships. These statistical tests tend to find the relationship between data groups and assist in verifying hypotheses about variables such as fingerprints, age, blood groups, and caste.

3. Results

During the collection of the primary data, 500 samples were collected from female participants in the different locations of Bahawalpur. During sample selection, 190 samples were excluded based on exclusion standards, among which 55.26% (N=105) were from institutional participants and 44.74% (N=85) were from town participants. Statistical analysis was applied to the remaining 310 samples (Table 1). The participants were divided into three groups based on age. Most of the participants were between 16-30 years old (93.2%), with the least percentage being 31-45 years old (3.2%) and 3.5% being in the age bracket of 46-60 years old (Table 2). The majority of the population belonged to the Arain Caste (26.5%), followed by Jutt (23.5%), Rajpoot (17.7%), Malik (12.9%), Syed (4.8%), Khan (4.2%), Mughal (3.9%), Sheikh (3.9%), and Baloch (2.6%) (Table 3). Blood group B was the most common (42.3%), followed by O (29%), A (21.9%), and the least common AB (6.8%) [Table 4]. Among all participants, the loop pattern was the most common (64.5%), followed by whorls (27.4%) and arches (8.1%) [Table 5].

A 1-sample t-test was conducted to find whether the means of variables (Cast, Blood Group, Age, and Fingerprint Patterns) significantly differ from a hypothesized population mean of 0. For Caste, the mean value is 3.2871 with a t-value of 25.065 and 309 degrees of freedom. The p-value (Sig. 2-tailed) is 0.000, below the standard threshold of 0.05, reflecting that the mean caste score significantly differs from the hypothesized value of 0. This suggests substantial variation in caste-related frequency across the sampled population. The blood group shows a mean value of 2.2065, with a t-value of 45.148 and 309 degrees of freedom. The p-value (Sig. 2-tailed) is 0.000, a significant difference from the test value of 0. This indicates a distinct variation in blood group distribution. The age has a mean value of 1.1032, with a t-value of 47.955 and 309 degrees of freedom. The p-value, 0.000, concludes that the age distribution shows a significant divergence from the hypothesized value

Table 1- *Frequency of samples included for statistical analysis*

		Caste	Blood Group	Age	Fingerprint Pattern
N	Valid	310	310	310	310
	Missing Entries	3	3	3	3

Table 2- *Frequency of age groups included in the study*

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	16-30	289	92.3	93.2	93.2
	31-45	10	3.2	3.2	96.5
	46-60	11	3.5	3.5	100.0
	Total	310	99.0	100.0	
Missing	System	3	1.0		
Total	313	100.0			

Table 3- *Frequency of castes included in the study*

	Caste	Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Arain	82	26.2	26.5	26.5
	Jutt	73	23.3	23.5	50.0
	Rajpoot	55	17.6	17.7	67.7
	Mughal	12	3.8	3.9	71.6
	Syed	15	4.8	4.8	76.5
	Malik	40	12.8	12.9	89.4
	Khan	13	4.2	4.2	93.5
	Baloch	8	2.6	2.6	96.1
	Sheikh	12	3.8	3.9	100.0
	Total	310	99.0	100.0	
Missing	System	3	1.0		
Total	313	100.0			

Table 4- *Frequency of blood groups included in the study*

	Blood Group	Frequency	Percent	Valid Percent	Cumulative Percent
Valid	A	68	21.7	21.9	21.9
	B	131	41.9	42.3	64.2
	O	90	28.8	29.0	93.2
	AB	21	6.7	6.8	100.0
	Total	310	99.0	100.0	
Missing	System	3	1.0		
Total		313	100.0		

Table 5- *Frequency of fingerprint patterns included in the study*

	Fingerprint Patterns	Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Arches	25	8.0	8.1	8.1
	Loop	200	63.9	64.5	72.6
	Whorl	85	27.2	27.4	100.0
	Total	310	99.0	100.0	
Missing	System	3	1.0		
Total		313	100.0		

and highlights distinct age-group characteristics among the population. The mean score of fingerprint patterns is 2.1935, with a t-value of 68.444 and 309 degrees of freedom. The p-value is 0.000, and it confirms a significant deviation from the test value of 0, indicating that the fingerprint pattern (arch, loop, and whorl) variations in the studied population [Table 6, 8-9].

The significant p-value for demographic variables indicates that these factors show variability and potentially influence fingerprint patterns. The distinct means of arches (4.2), loops (3.6), and whorls (2.85) suggest that ridge patterns align differently across demographic variables [Table 7]. The 1-sample t-test outcomes show that demographic factors significantly show association with fingerprint patterns. This highlights the potential interplay between demographic characteristics and fingerprint patterns variability in the studied sample.

A one-way NOVA was performed to determine whether the demographic factors have a significant impact on fingerprint patterns. In the case of

Table 6- *Summary of cases processed*

	Cases					
	Included		Included		Included	
	N	Percent	N	Percent	N	Percent
Caste*Fingerprint pattern	310	99.0%	3	1.0%	313	100.0%
Blood Group*Fingerprint pattern	310	99.0%	3	1.0%	313	100.0%
Age*Fingerprint pattern	310	99.0%	3	1.0%	313	100.0%

Table 7- *No. of samples, mean and standard deviation of demographic factors, and fingerprint patterns*

Fingerprint Pattern		Caste	Blood Group	Age
	Mean	4.2000	2.4000	1.0800
Arches	N	25	25	25
	Std. Deviation	2.81366	1.00000	40000.
	Mean	3.3600	2.1600	1.1050
Loop	N	200	200	200
	Std. Deviation	2.32323	85325.	41815.
	Mean	2.8471	2.2588	1.1059
Whorl	N	85	85	85
	Std. Deviation	2.02664	83314.	37870.
	Mean	3.2871	2.2065	1.1032
Total	N	310	310	310
	Std. Deviation	2.30901	86047.	40505.

Table 8- *Statistics for 1-sample t-test*

	N	Mean	Std. Deviation	Std. Error Mean
Caste	310	3.2871	2.30901	13114.
Blood Group	310	2.2065	86047.	04887.
Age	310	1.1032	40505.	02301.
Fingerprint Pattern	310	2.1935	56427.	03205.

Table 9- *Results of 1-sample t-test*

	Test Value = 0					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Lower
Caste	25.065	309	.000	3.28710	3.0291	3.0291
Blood Group	45.148	309	.000	2.20645	2.1103	2.1103
Age	47.955	309	.000	1.10323	1.0580	1.0580
Fingerprint Pattern	68.444	309	.000	2.19355	2.1305	2.1305

Table 10- *Descriptive statistics for one-way ANOVA*

		N	Mean	Std. Devia-tion	Std. Error Lower Bound	95% Confidence Interval for Mean		Minimum	Maximum
						Upper bound			
Caste	Arches	25	4.2000	2.81366	.56273	3.0386	5.3614	1.00	9.00
	loop	200	3.3600	2.32323	.16428	3.0361	3.6839	1.00	9.00
	whorl	85	2.8471	2.02664	.21982	2.4099	3.2842	1.00	9.00
	Total	310	3.2871	2.30901	.13114	3.0291	3.5451	1.00	9.00
Blood Group	Arches	25	2.4000	1.00000	.20000	1.9872	2.8128	1.00	4.00
	loop	200	2.1600	.85325	.06033	2.0410	2.2790	1.00	4.00
	whorl	85	2.2588	.83314	.09037	2.0791	2.4385	1.00	4.00
	Total	310	2.2065	.86047	.04887	2.1103	2.3026	1.00	4.00
Age	Arches	25	1.0800	.40000	.08000	.9149	1.2451	1.00	3.00
	loop	200	1.1050	.41815	.02957	1.0467	1.1633	1.00	3.00
	whorl	85	1.1059	.37870	.04108	1.0242	1.1876	1.00	3.00
	Total	310	1.1032	.40505	.02301	1.0580	1.1485	1.00	3.00

Caste, the analysis shows a statistically significant difference in fingerprint patterns with an F-value of 3.659 and a p-value of 0.027. This showed that the mean fingerprint patterns vary significantly across different caste groups. The descriptive statistics showed mean fingerprint pattern scores of 4.2 for arches, 3.36 for loops, and 2.85 for whorls. Post hoc Tukey tests identified that the difference between arches and whorls was significant (p = 0.027), indicating that certain fingerprint patterns are widespread in specific caste groups. For the Blood Group, the ANOVA gave an F-value of 1.082 and a p-value of 0.3400, which was not statistically significant. This indicated that there was no meaningful variation in fingerprint patterns across the different blood groups. The mean fingerprint pattern values for arches, loops, and whorls were quite close at 2.4, 2.16, and 2.26, respectively, confirming the lack of significant difference. ANOVA analysis of age had an F-value of 0.045 with a

Table 11- *Results of one-way ANOVA test*

		Sum of Squares	df	Mean Square	F	Sig.
Caste	Between Groups	38.357	2	19.178	3.659	.027
	Within Groups	1609.092	307	5.241		
	Total	1647.448	309			
Blood Group	Between Groups	1.601	2	.801	1.082	.340
	Within Groups	227.186	307	.740		
	Total	228.787	309			
Age	Between Groups	.015	2	.007	.045	.956
	Within Groups	50.682	307	.165		
	Total	50.697	309			

Table 12- *Post Hoc Tukey test*

Dependent Variable	(I)Fingerprint Pattern	(J)Fingerprint Pattern	Mean Difference (I – J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Caste	Arches	Loop	.84000	.48565	.196	-.3038	1.9838
		Whorl	1.35294*	.52088	.027	.1262	2.5797
	Loop	Arches	-.84000	.48565	.196	-1.9838	.3038
		Whorl	.51294	.29643	.196	-.1852	1.2111
	Whorl	Arches	-1.35294*	.52088	.027	-2.5797	-.1262
		Loop	-.51294	.29643	.196	-1.2111	.1852
Blood Group	Arches	Loop	.24000	.18249	.388	-.1898	.6698
		Whorl	.14118	.19572	.751	-.3198	.6021
	Loop	Arches	-.24000	.18249	.388	-.6698	.1898
		Whorl	-.09882	.11138	.649	-.3611	.1635
	Whorl	Arches	-.14118	.19572	.751	-.6021	.3198
		Loop	.09882	.11138	.649	-.1635	.3611
Age	Arches	Loop	02500.-	08619.	955.	2280.-	1780.
		Whorl	02588.-	09244.	958.	2436.-	1918.
	Loop	Arches	02500.	08619.	955.	1780.-	2280.
		Whorl	00088.-	05261.	1.000	1248.-	1230.
	Whorl	Arches	02588.	09244.	958.	1918.-	2436.
		Loop	00088.	05261.	1.000	1230.-	1248.

Table 13- *Tukey's honestly significant difference test for caste*

Fingerprint Pattern	N	Subset for alpha = 0.05	
		1	2
Whorl	85	2.8471	
Loop	200	3.3600	3.3600
Arches	25		4.2000
Sig.		.483	.144

Table 14- *Tukey's honestly significant difference test for blood*

Fingerprint Pattern	N	Subset for alpha = 0.05
		1
Whorl	200	2.1600
Loop	85	2.2588
Arches	25	2.4000
Sig.		.325

Table 15- *Spearman correlation test for blood group and fingerprint pattern*

Variable	N	Blood Group	Fingerprint Pattern	Sig. (2-tailed)
Blood Group	310	1	-0.003	0.964
Fingerprint Pattern	310	-0.003	1	0.964

Table 16- *Spearman's Rank correlation test for blood group and fingerprint pattern*

Variable	N	Blood Group	Fingerprint Pattern	Sig. (2-tailed)
Blood Group	310	1.000	0.018	0.749
Fingerprint Pattern	310	0.018	1.000	0.749

p-value of 0.956, and indicated that there was no significant relationship between fingerprint patterns and age groups. The meant that for all fingerprint patterns across the age groups were consistent, with minimal variations [Table 10-14].

Among all the demographic factors, socio-demographic factors like caste showed a statistically significant association with fingerprint patterns (particularly between the arches and whorls). In contrast, biological factors like age and blood group were not significant predictors of ridge patterns, as no substantial differences were observed across these groups.

Pearson Correlation and Spearman's Rank Correlation tests were applied to analyze the relationships between demographic factors, blood groups and caste, and fingerprint patterns. The Pearson correlation coefficient between blood group and fingerprint patterns is -0.003. It shows no linear relationship between them. The p-value (Sig. 2-tailed) of 0.964 was higher than the standard threshold of 0.05, proving that there exists no statistically significant relationship. Thus, in a linear context, fingerprint patterns were independent of the blood group [Table 15]. The Spearmen's Rank correlation was 0.018, indicating a negligible association between blood group and fingerprint patterns. The p-value of 0.749, reflected no significant relationship in a non-linear context. These aligned with the Pearson test, showing no correlation between blood groups and fingerprint patterns [Table 16].

The Pearson correlation coefficient between caste and fingerprint patterns was -0.150. It showed a weak negative linear relationship between them. The p-value (Sig. 2-tailed) of 0.008 was less than 0.01, indicating that the relationship was statistically significant at the 1% level. This shows that as caste changes between different groups, there is a small but consistent shift in the fingerprint patterns

Table 17- *Pearson correlation test for caste and fingerprint pattern*

Variable	N	Caste	Fingerprint Pattern	(Sig. (2-tailed
Caste	310	1	-0.150	0.008
Fingerprint Pattern	310	-0.150	1	0.008

Table 18- *Spearman's Rank correlation test for caste and fingerprint pattern*

Variable	N	Caste	Fingerprint Pattern	Sig. (2-tailed)
Caste	310	1	-0.1333	0.019
Fingerprint Pattern	310	-0.1333	1	0.019

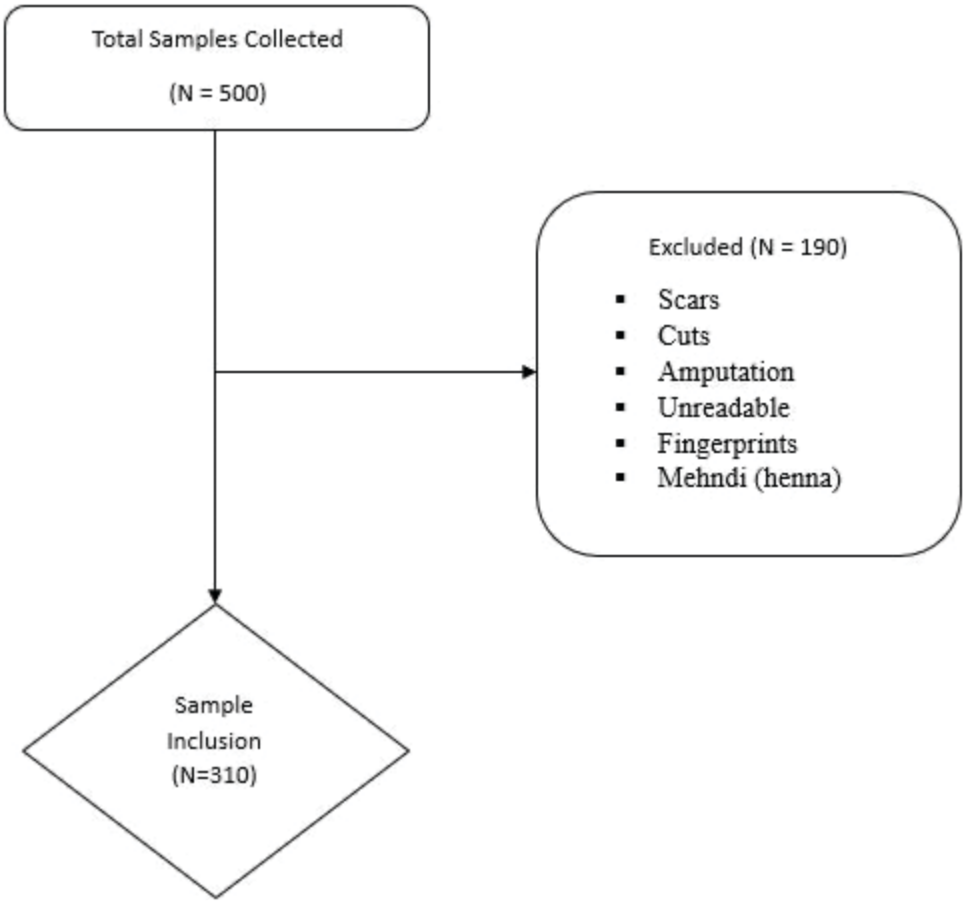

Fig. 1- *Flowchart showing the sample selection process for studying demographic variability in fingerprint patterns*

distribution [Table 17]. The Spearmen's Rank correlation was -0.133, indicating a weak negative association between caste and fingerprint patterns. The p-value of 0.019 was below 0.05, which affirmed that the relationship was statistically significant at the 5% level. This relationship was weaker than the Pearson correlation test still; it indicated that fingerprint patterns vary subtly with caste [Table 18).

The results show that caste is a significant factor linked with fingerprint patterns by both Pearson and Spearman correlation tests. Nevertheless, the relationship is weak and negative, signifying only a subtle influence. Due to negligible correlation coefficients and high p-values, the blood group has no significant relationship with fingerprint patterns. This shows that fingerprint patterns are independent of biological traits but slightly influenced by socio-demographic factors such as caste.

4. Discussion

Analysis of fingerprint patterns has long been regarded as a significant tool in forensic investigations, personal identification, etc. However, the extent to which demographic characteristics impact fingerprint patterns remain an area of many research studies. This study was conducted to explore these associations among female individuals in the Bahawalpur region of Punjab province, Pakistan, providing empirical evidence regarding the significance of these factors in fingerprint pattern variations. Unlike other variables such as age, blood group, and gender, caste is included for the first time in any research study related to fingerprint patterns. The results of prior studies were based on basic observation of particular factors, but this study investigates each factor statistically. The statistical analyses, including one-sample t-tests, one-way ANOVA, and correlation tests, offered critical insights into these relationships.

The results disclosed that fingerprint patterns (arches, loops, and whorls) exhibit substantial diversity within the population studied. Among the demographic variables considered, caste emerged as a statistically significant factor linked with fingerprint pattern variations. The one-way ANOVA results indicated a significant difference in fingerprint patterns across caste groups ($F = 3.659$, $p = 0.027$). Post hoc analyses further confirmed that specific fingerprint patterns, particularly arches and whorls, showed notable differences between certain caste or racial groups. Correlation analyses supported these findings, as both Pearson ($r = -0.150$, $p = 0.008$) and Spearman ($r = -0.133$, $p = 0.019$) correlation coefficients indicated a weak but statistically significant negative association between caste and fingerprint patterns. These results suggest that fingerprint patterns distribution is not entirely random and may be subtly influenced by socio-demographic or ancestral backgrounds. The blood group was found to have no significant relationship with fingerprint patterns. The one-way ANOVA ($F = 1.082$, $p = 0.340$) and correlation tests (Pearson $r = -0.003$, $p = 0.964$; Spearman $r = 0.018$, $p = 0.749$) confirmed the absence of any meaningful association. These findings align with previous studies that have reported negligible or inconsistent correlations between blood group and fingerprint pattern characteristics. The lack of a significant relationship suggests that blood group, a genetically inherited trait, does not influence fingerprint patterns, which are determined by complex polygenic factors during fetal development. Age showed no significant impact on fingerprint pattern distribution. The ANOVA results ($F = 0.045$, $p = 0.956$) and correlation analyses indicated no meaningful variation in fingerprint patterns across different age groups. This finding is consistent with established forensic literature, which suggests that fingerprint patterns remain stable throughout an individual's lifetime. The lack of age-related variation reinforces the reliability of fingerprints as a lifelong biometric identifier, further supporting their use in forensic applications.

The observed association between caste and fingerprint patterns may be credited to genetic and environmental influences. Certain studies propose that fingerprint patterns are influenced by hereditary traits which are more prevalent in populations with shared ancestry. This could explain the subtle differences in fingerprint patterns across castes. However, the relatively weak correlation values indicate that caste may play a role. Future studies with larger, ethnically diverse samples and genetic analyses are necessary to further investigate these associations.

The results of this research study hold several implications for forensic investigations. This has potential applications in forensic investigations where unidentified fingerprint evidence may provide clues about an individual's demographic background. As the correlation is weak, caste ancestry alone cannot be a definitive determinant of fingerprint pattern distribution. The lack of association between blood groups and fingerprint patterns emphasizes the idea that fingerprint pattern variability is not influenced by blood type, which may be relevant to forensic profiling. Since blood group classification is frequently used in forensic cases involving bloodstain analysis, it is important to note that no direct link exists between a person's blood type and their fingerprint pattern, statistically. This finding adds to the existing body of research dismissing claims of a connection between blood group and dermatoglyphic traits. Similarly, the finding that age does not affect fingerprint patterns confirms the permanence of fingerprints which is a fundamental principle in forensic science. This supports the continued use of fingerprint pattern analysis as a reliable method of personal identification in forensic and security applications as fingerprint pattern patterns do not change over time.

In spite of its valuable contributions, this research study has several limitations that should be addressed in future research. The study focused exclusively on females in Bahawalpur which limits the generalizability of the findings to males and populations in other geographical regions. Previous studies suggest that fingerprint pattern distributions may vary between males and females, so future research should incorporate gender-based comparisons. The classification of caste was not based on genetic analysis but rather on self-reported demographic data. While caste is often associated with genetic ancestry, they are also influenced by social and cultural factors. Future studies should integrate genetic analysis to determine whether specific genetic markers correlate with fingerprint pattern variations. Finally, the study relied on a relatively small sample size (N = 310). While the results provide meaningful insights, a larger and more diverse sample would enhance the statistical power of the findings. Expanding the study to include a broader range of ethnic groups would also provide a more comprehensive understanding of fingerprint pattern variability across populations.

5. Conclusion

The study of demographic variability in fingerprint patterns has revealed that statistically, caste is the only factor that has some relationship with ridge patterns on fingers. However, blood group and age are not statistically linked with fingerprint patterns. Although prior qualitative studies have tended to explore the associations between these factors and fingerprint patterns exist, it is proven statistically in our sampled population. This contributes to forensic science by expanding the scope of analysis of fingerprint patterns beyond traditional identification factors. Integrating demographic variables into analysis by forensic practitioners can improve the precision of individual profiling. There is a need to develop guidelines for applying these factors to forensic protocols to enhance the evidentiary value of such fingerprint pattern analysis in courtrooms. This can be supported by future research studies at large scales across diverse populations to investigate demographic patterns among regional groups or races and validate existing findings.

Conflict of interest

The authors declare no conflicts of interest.

Source of funding

The authors received no financial support for the research, authorship or publication of this paper.

References

1. Mac1kenzie, P. (2022). Nehemiah Grew, the illustrator. Notes and Records. https://doi.org/10.1098/rsnr.2022.0020
2. Cole, S. A. (2007). History of Fingerprint Pattern Recognition. In Automatic Fingerprint Recognition Systems (pp. 1–25). https://doi.org/10.1007/0-387-21685-5_1
3. Faulds, H., & Herschel, W. J. (2015). Dactylography and The Origin of Finger-Printing. Cambridge University Press. (Original work published 1912). https://doi.org/10.1017/CBO9781316146521
4. Francis Galton: Fingerprinter. (n.d.). Galton.org. https://galton.org/fingerprinter.html
5. Maltoni, D., Maio, D., Jain, A. K., & Prabhakar, S. (2009). Handbook of Fingerprint Recognition. Springer London. https://doi.org/10.1007/978-1-84882-254-2
6. Champod, C., Lennard, C., Margot, P., & Stoilovic, M. (2016). Fingerprints and Other Ridge Skin Impressions, Second Edition. In International Forensic Science and Investigation. CRC Press. https://doi.org/10.1201/b20423
7. AFIS (Automated Fingerprint Identification System). (n.d.). Innovatrics. https://www.innovatrics.com/glossary/afis-automated-fingerprint-identification-system/
8. Acree, M. A. (1999). Is there a gender difference in fingerprint ridge density? Forensic Science International, 102(1), 35–44. https://doi.org/10.1016/s0379-0738(99)00037-7
9. Venkatesh, M., Vitthal, K., Dundesh, M., Ambuj, J., Shilpa, M., & Komal, R. (2015). Pattern of Fingerprints in Different ABO and Rh Blood Groups. Journal of Indian Academy of Forensic Medicine, 37(2). https://www.indianjournals.com/ijor.aspx?target=ijor:jiafm&volume=37&issue=2&article=002
10. Sánchez-Andrés, A., Barea, J. A., Rivaldería, N., Alonso-Rodríguez, C., & Gutiérrez-Redomero, E. (2018). Impact of aging on fingerprint ridge density: Anthropometry and forensic implications in sex inference. Science & Justice, 58(5), 323–334. https://doi.org/10.1016/j.scijus.2018.05.001
11. Prabhakar, S., Pankanti, S., & Jain, A. K. (2003). Biometric recognition: security and privacy concerns. IEEE Security & Privacy Magazine, 1(2), 33–42. https://doi.org/10.1109/msecp.2003.1193209
12. Cole, S. A. (2002). Suspect Identities — Harvard University Press. In Harvard University Press. Harvard University Press. https://www.hup.harvard.edu/books/9780674010024
13. LH, A., & MG, T. (2017). Embryogenesis and Applications of Fingerprints- a review. International Journal of Human Anatomy, 1(1), 1–8. https://doi.org/10.14302/issn.2577-2279.ijha-17-1539
14. Babler, W. J. (1991). Embryologic development of epidermal ridges and their configurations. Birth Defects Original Article Series, 27(2), 95–112. https://pubmed.ncbi.nlm.nih.gov/1786361/
15. Hale, A. R. (1952). Morphogenesis of volar skin in the human fetus. American Journal of Anatomy, 91(1), 147–181. https://doi.org/10.1002/aja.1000910105
16. Hirsch, W., & schweighel, J. U. (2008). Morphological Evidence Concerning The Problem Of Skin Ridge Formation. Journal of Intellectual Disability Research, 17(1), 58–72. https://doi.org/10.1111/j.1365-2788.1973.tb01186.x
17. Okajima, M. (1975). Development of dermal ridges in the fetus. Journal of Medical Genetics, 12, 243. https://doi.org/10.1136/jmg.12.3.243

18. Penrose, L. S., & Ohara, P. T. (1973). The development of the epidermal ridges. Journal of Medical Genetics, 10(3), 201–208. https://doi.org/10.1136/jmg.10.3.201
19. Kücken, M., & Newell, A. C. (2004). A model for fingerprint formation. Europhysics Letters (EPL), 68(1), 141–146. https://doi.org/10.1209/epl/i2004-10161-2
20. Henry, E. R. (1900). Classification and Uses of Finger Prints. In collections.nlm.nih.gov. George Routledge and Sons, Limited. https://collections.nlm.nih.gov/catalog/nlm:nlmuid-1306026-bk
21. Ashbaugh, D. R. (1999). Quantitative-Qualitative Friction Ridge Analysis. CRC Press.
22. Forensic Science Simplified. (2013). Fingerprint analysis: Principles. Www.forensicsciencesimplified.org. https://www.forensicsciencesimplified.org/prints/principles.html
23. Types Of Fingerprint Patterns - Forensic's blog. (2022). Forensicfield.blog. https://forensicfield.blog/types-of-fingerprint-patterns/
24. Gupta, A., & Singh, B. (2024). Fingerprint-Based Prediction of Gender: An Important tool in Criminal Investigation. Journal of Indian Academy of Forensic Medicine, 46(2), 224–226. https://doi.org/10.48165/jiafm.2024.46.2.6
25. Shrestha, D. B., Gupta, V. P., Chaurasiya, P. S., Shrestha, S., & Aryal, L. (2016). Study of Correlation between Different Fingerprint Patterns, Blood Groups, and Social Behavior among Medical Students (Nepalese Citizens). The Pacific Journal of Science and Technology, 17(2), 288–292.
26. Wertheim, K., & Maceo, A. (2002). The Critical Stage of Friction Ridge and Pattern Formation. Journal of Forensic Identification, 52(1), 35. https://evolveforensics.com/wp-content/uploads/2015/07/Wertheim-and-Maceo.-The-Critical-Stage-of-Friction-Ridge-and-Pattern-Formation.pdf
27. Burger, B., Fuchs, D., Sprecher, E., & Itin, P. (2011). The immigration delay disease: Adermatoglyphia–inherited absence of epidermal ridges. Journal of the American Academy of Dermatology, 64(5), 974–980. https://doi.org/10.1016/j.jaad.2009.11.013
28. Matton, M., De Bie, S., & Anseeuw, A. (1981). Familial dermatoglyphic analysis in syndactyly type I. The Journal of Hand Surgery, 6(6), 537–542. https://doi.org/10.1016/s0363-5023(81)80124-4
29. Slatis, H. M., Katznelson, M. B., & B Bonné-Tamir. (1976). The inheritance of fingerprint patterns. American Journal of Human Genetics, 28(3), 280. https://pmc.ncbi.nlm.nih.gov/articles/PMC1685016/
30. Can you determine race from a fingerprint? (2015). DNA Project – South Africa. https://dnaproject.co.za/can-you-determine-race-from-a-fingerprint/
31. Swofford, H. J. (2005). Fingerprint patterns: A study on the finger and ethnicity prioritized order of occurrence. 55(4), 480–488. https://www.researchgate.net/publication/292220493_Fingerprint_patterns_A_study_on_the_finger_and_ethnicity_prioritized_order_of_occurrence
32. McCombes, S. (2021). How to create a research design. Scribbr. https://www.scribbr.com/methodology/research-design/
33. Bhat, A. (2019). Data Collection Methods: Definition, Examples and Sources | QuestionPro. QuestionPro. https://www.questionpro.com/blog/data-collection-methods/
34. Bhat, A. (2018). Research Design: Definition, Characteristics and Types | QuestionPro. QuestionPro. https://www.questionpro.com/blog/research-design/
35. DATAtab Team. (2024). DATAtab: Online Statistics Calculator. DATAtab e.U. Graz, Austria. Datatab.net. https://datatab.net/tutorial/one-sample-t-test
36. Carpenter, A. (2022). What is ANOVA (analysis of variance) and what it's used for. Qualtrics. https://www.qualtrics.com/experience-management/research/anova/
37. JMP. (n.d.). Correlation. Www.jmp.com. https://www.jmp.com/en_ca/statistics-knowledge-portal/what-is-correlation.html