Footprint Analysis for Comparative Study of Populations

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Abstract: In the past many studies have been conducted to estimate age, sex, stature, etc. of an individual from footprints. Footprint is one important evidence which cannot be erased completely since "it needs to go somewhere to do something". In present study, inked footprints of the individuals of Himachal Pradesh and Delhi were studied to get an idea of the basic differences between the footprints of the two communities. Measurements of various angles and lengths were performed using protectors and scales. Various parameters were set and analyzed. It was observed that parameters foot breadth, foot length, alpha angle, etc. gave good significant results whereas first toe length,phalange marks and foot index, etc. gave non- significant results when the two populations were compared. Various statistical formulas were applied and it was observed that, 11 out of 25 parameters gave significant results. This study suggests that using these 11 significant parameters, an expert can get an estimate of whether the footprint found at any crime scene belongs to Delhi population or Himachal Pradesh population.

Keywords: Forensic Science, Anthropometry, Stature, Region.

I. INTRODUCTION

In forensic sciences, the identification of individuals involved in crime has always remained a mainstay. The scientific study of the formation of naturally occurring ridges on body parts is referred as dermatoglyphics. The ridges can be found on palms, fingers, soles and toes [1]. Some variations in the dimensions of the ridges are result of the growth of an individual. Anthropologists, forensic scientists, physicians, anatomists, and human biologists have studied these ridges innumerous analyses and have yield very useful results. According to Dr. Edmond Locard, "Every contact leaves a trace" [2]

It is certain that at every scene of crime, the suspect, perpetrator or criminal will leave a mark that will help the forensic scientist to establish relation between the culprit and the scene of crime. The evidences reflect the class and individual characteristics of a person. At a crime scene, one of the valuable evidence (physical

evidence) that a suspect leaves unintentionally is likely to include footprints, which can provide vast and useful information to establish a person's identity and ease the process of crime investigation. The human foot, which provides the vast information about the person, consists of 26 major bones and numerous synovial joints and forms a highly complex structure [3]. These play a major role in both: supporting the load bore by the body, act as shock absorbers and provides stabilization and balance to the body while walking, running and jogging [4]. The human foot morphology can vary considerably. These variations in humans can be attributed due to the combined effects of lifestyle, heredity as well as climatic factors [5]. Similar to fingerprints, footprints are also unique to an individual and can provide a linkage to a crime. Footprints can also act as a means of confirming and also ruling out the involvement of an individual in that crime. The study of footprints in country like India, where a large number of people prefer to walk barefoot due to socio-economic, climatic and religious reasons has a considerable value in Forensic Sciences. Footprints are

generally encountered in India at various crime sites and if the detailed analysis of footprint evidence at the scene of crime is done it can become a vital evidence for linking the suspect to the crime scene. Footprint as an evidence can be found and collected from almost every scene of crime. Foot morphology can also help in estimating the body size (stature, body weight, etc.) of the criminals.

On the basis of footprints one can estimate – Sex of the individual[6][7][8], stature[8][9][10][11][12][13][14][15], weight of the individual[10][11][15], if a person is carrying load or walking backward, the arch index[16][17] i.e. if person is having high foot or flat foot condition, gait pattern – foot angle, foot line, direction line, step length, step width, principle angle, gate line, bodily pressure, foot parameter, deformities, body ratio, walking pattern, the force exerted on each foot, the angle of declination between toes, arch height. The footprint pattern is also work specific i.e. the pattern of footprint of an individual changes according to the type of profession he has[18].Studies have been conducted for stature determination of an individual by measuring long bones and also by doing various percutaneous body measurements[12][13][14].

Length of the foot shows a biological correlation with the height. Foot length can help in estimating stature. For identification purposes also, the foot can play a major role, as it is protected by the socks and shoes. Studies have been done in which attempts have been made to establish a relation between the foot dimensions and the stature[11].

In the past similar studies have been conducted by TKanchan in 2008to estimate stature from foot dimensions[19]. Sarah Reel in 2012, have also estimated stature on observing static and dynamic footprints[20]. Similar studies were performed on Indian Tamils populations by TN Moorthy in 2014 and using regression formulas the stature was estimated[21].

Some work has been done previously also to study the footprints of different populations and determining various parameters from them, such as a study was conducted on Ghanian population by Jubilant Kwame Abledu in 2015, to determine sex from footprints[6]. A similar study was conducted by T. Nataraja Moorthy and Siti Fatimah Binti Sulaiman in 2014 on Malasian malays for personal identification through footprints[22].Haryanvi Jat population was also studied by Sween Walia in 2016 to determine sexual dimorphism from foot dimensions[23]. Some studied were also done on Central Indian population[24].

With the help of this study, first time, an attempt was made to compare the populations of Delhi and Himachal Pradesh on the basis of barefoot prints by making a database of foot imprints measurement using anthropometry.

II.   MATERIALS AND METHODOLOGY

A glass slab was taken and cleaned with cotton dipped in 70% alcohol. Approximately 3 gram black ink was taken on the cleaned glass slab and spread uniformly with a roller. The sole of the right foot of the subject was cleaned with cotton so as to remove dust particles. The roller was then first rolled over the prepared slab so that the ink got spread uniformly on the roller body

and then the roller was rolled over the sole of the subject. The subject was then asked to stand up and step his foot on a white A4 sheet. The impression formed was left to air dry for 1-2 minutes. The measurements on the dried samples were done using a protector, a 15 cm scale and a 12 inch scale. The data was then entered into the Microsoft excel software and statistical formulas were applied.

OBSERVATION

The study was conducted to check whether there was any difference between the footprints of the populations of Himachal Pradesh and Delhi. The age of the subjects ranged between 18 and 30 years. The parameters stated below were assigned by the researcher to various points and lengths on the footprint samples. Various measurements were performed and recorded parameters were studied for significant and insignificant results. The following table gives the list of parameters used during the study.

S. No.	PARAMET-ERS	EXPLANATION
1	ALPHA (α)	Angle between first toe and second toe.
2	BETA (β)	Angle between first toe and third toe.
3	GAAMA (ꞩ)	Angle between first toe and fourth toe.
4	THEETA (θ)	Angle between first toe and fifth toe.
5	SIE (ʒ)	Foot Angle
6	AB	Maximum width at the metatarsal.
7	CD	Maximum width at the heel.
8	AC	Length of inner tangent from metatarsal to heel i.e; A to C.

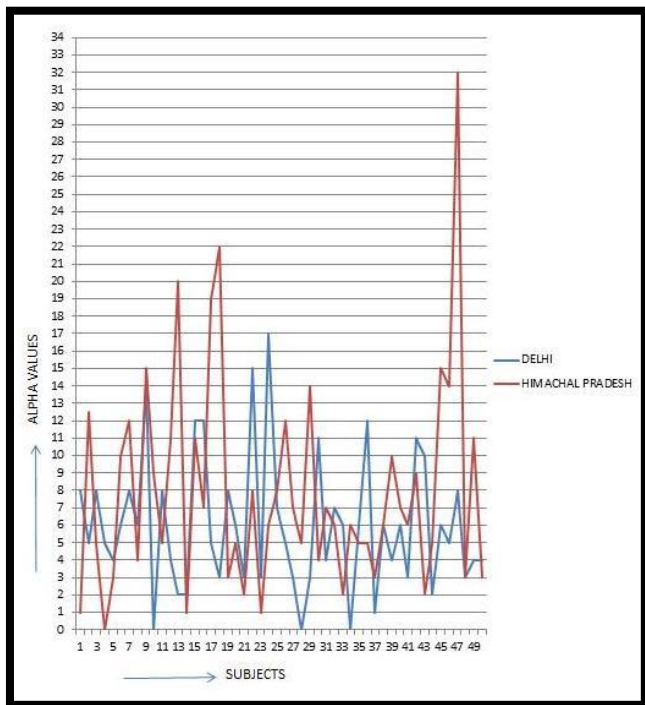| 9	BD	Length of outer tangent from metatarsal to heel i.e; B to D.
10	$X\text{-}X^I$	Distance from pternion to top most point on first toe.
11	$X\text{-}X^{II}$	Distance from pternion to top most point on second toe.
12	$X\text{-}X^{III}$	Distance from pternion to top most point on third toe.
13	$X\text{-}X^{IV}$	Distance from pternion to top most point on fourth toe.
14	$X\text{-}X^{V}$	Distance from pternion to top most point on fifth toe.
15	$X^I\text{-}X^{II}$	Distance between first toe and second toe.
16	$X^{II}\text{-}X^{III}$	Distance between second toe and third toe.
17	$X^{III}\text{-}X^{IV}$	Distance between third toe and fourth toe.
18	$X^{IV}-X^{V}$	Distance between fourth toe and fifth toe.
19	FOOT LENGTH	Distance between acropodian and the pternion.
20	FOOT WIDTH	Distance between metatarsal fibula and metatarsal tibia.
21	PHALANGE MARKS	The ridges connecting toes with the mid foot.
22	HUMPS	Raised area on the mid foot.
23	FIRST TOE LENGTH	Maximum length of first toe.
24	FIRST TOE BREADTH	Maximum width of first toe.
25	FOOT INDEX	Percentage of length v/s width of the foot.

Table 1: Parameters undertaken for study.
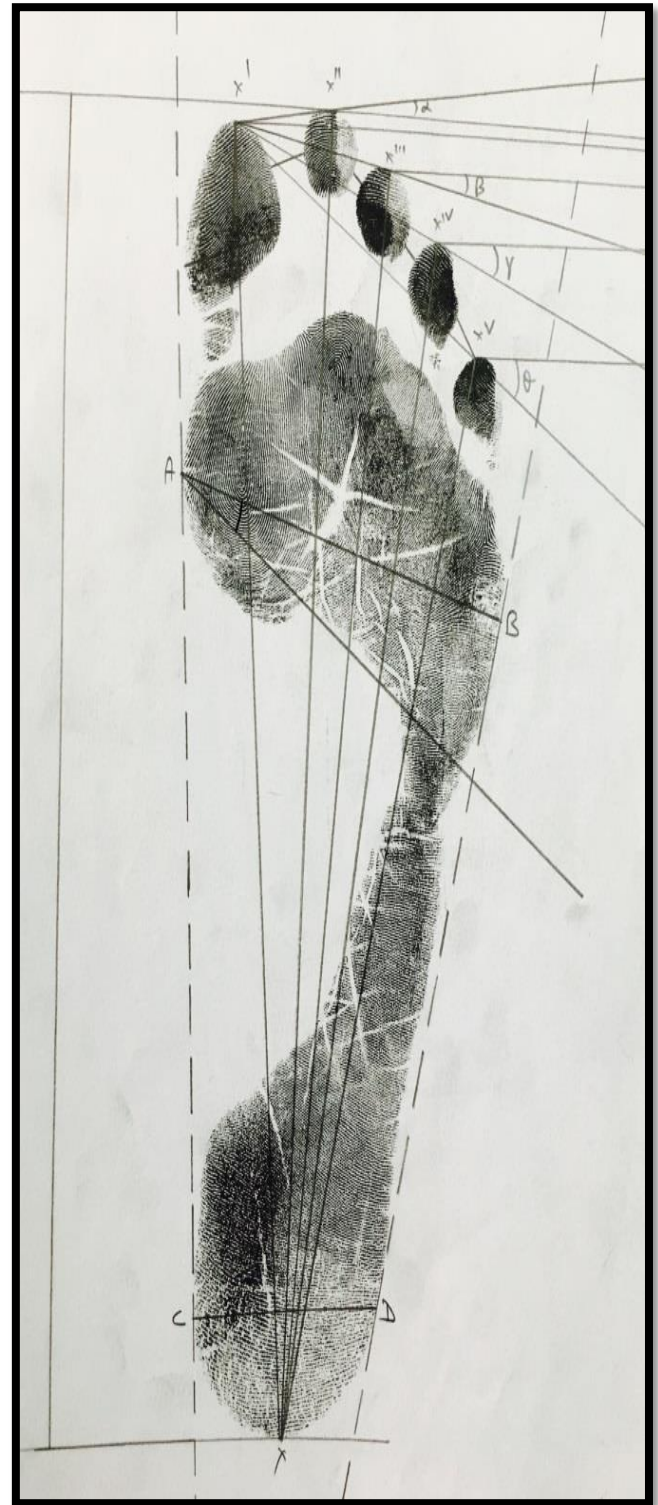
**Figure-1**: Representation of parameters undertaken for study.

Tables and graphs were prepared from the data collected on the basis of measurements from the above stated parameters. Various mathematical and statistical formulas were applied on the data collected and results were formulated.
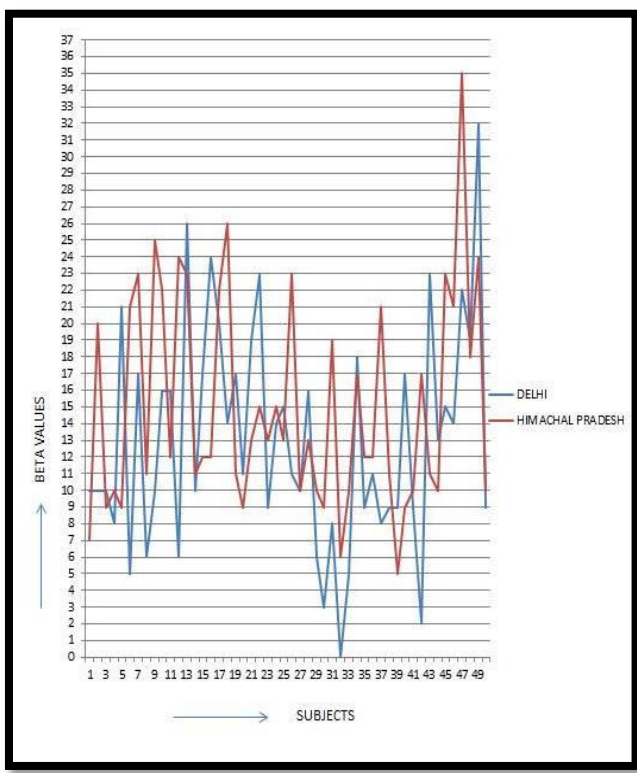
III.   GRAPHS

The following graphs show the comparison of the subjects of the two populations in reference to the parameters stated above in Table-1.
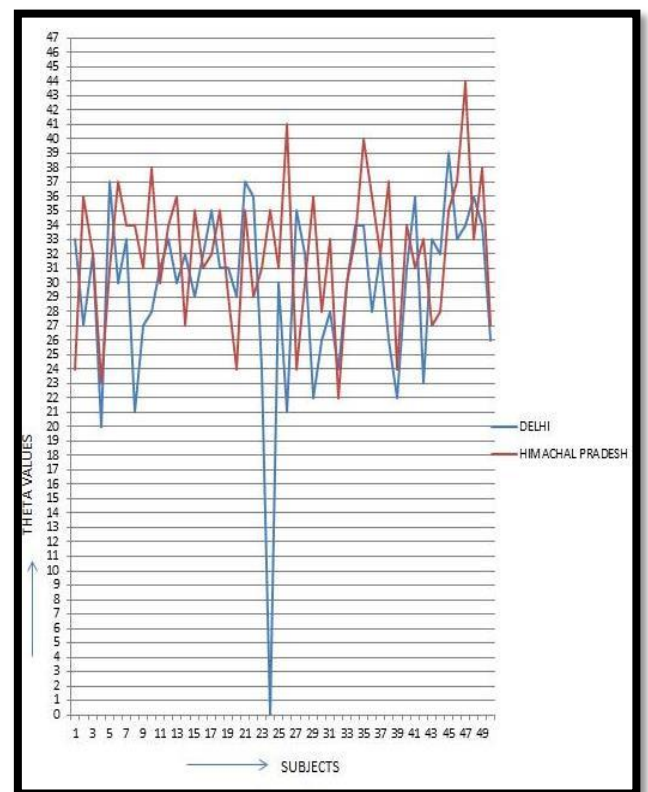

Graph 1: Alpha Values(Angle between first toe and second toe).
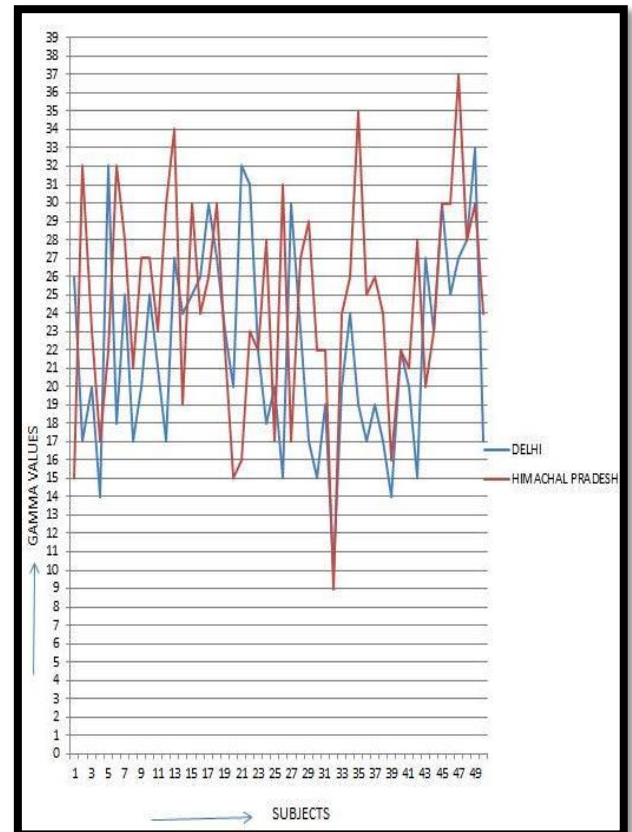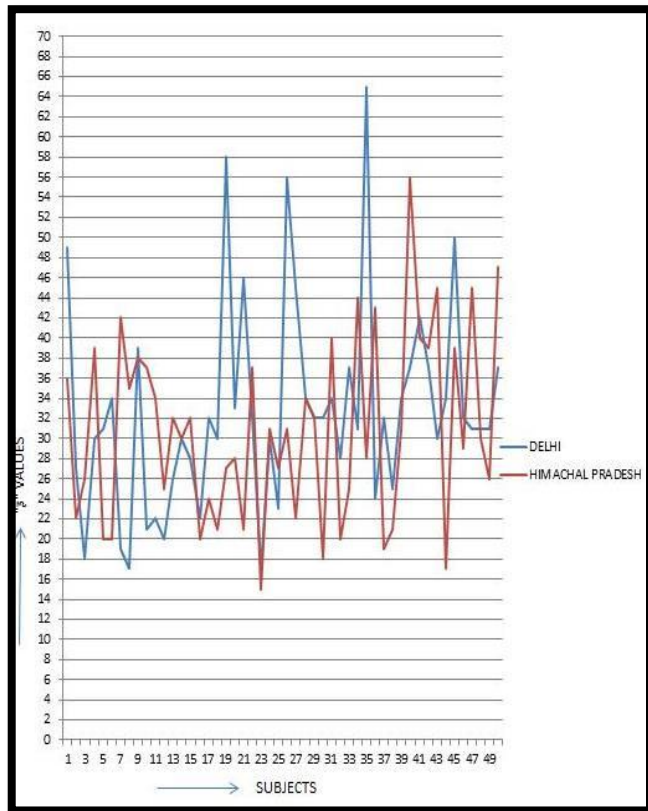

Graph 3: Gamma Values (Angle between first toe and fourth toe).
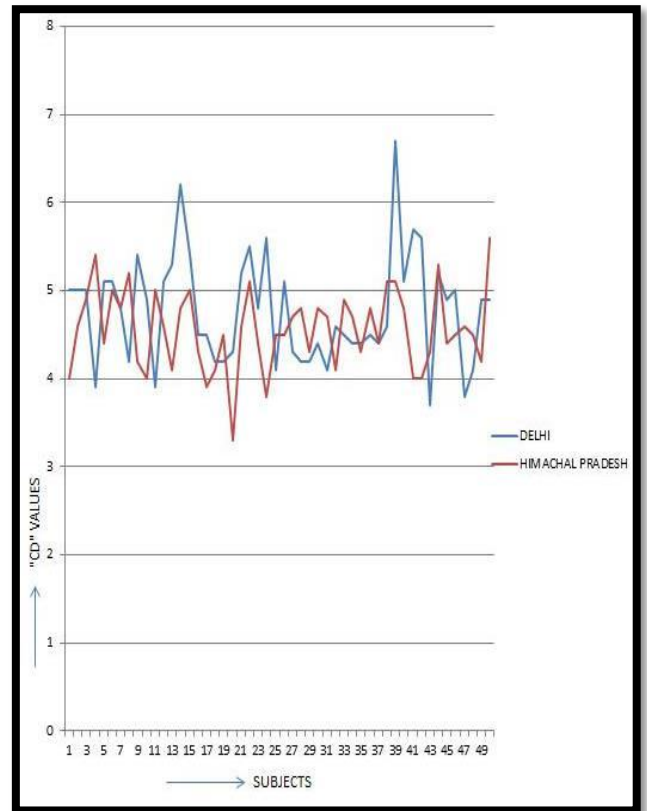

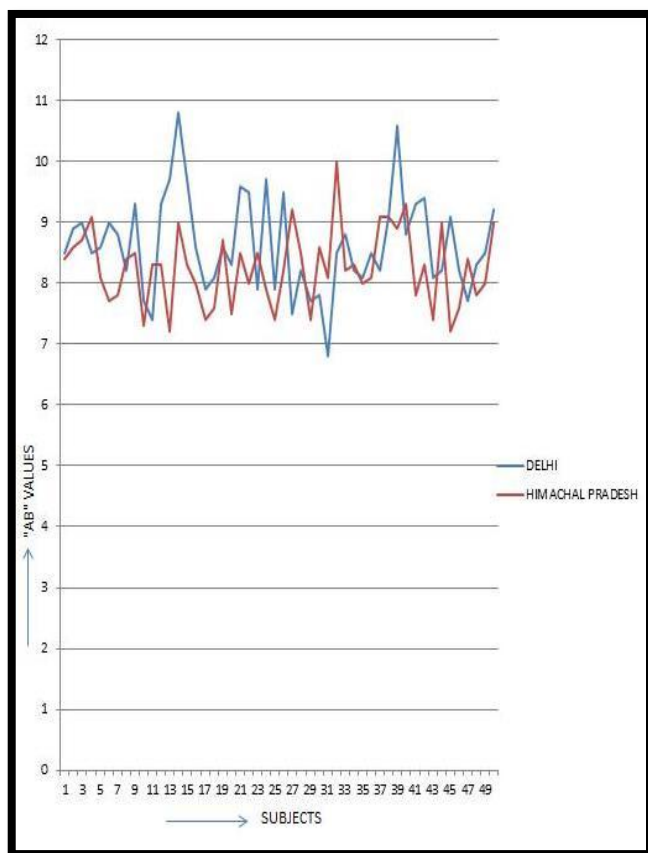**Graph 2: Beta Values** (Angle between first toe and third toe).

Graph 4: Theeta Values (Angle between first toe and fifth toe).
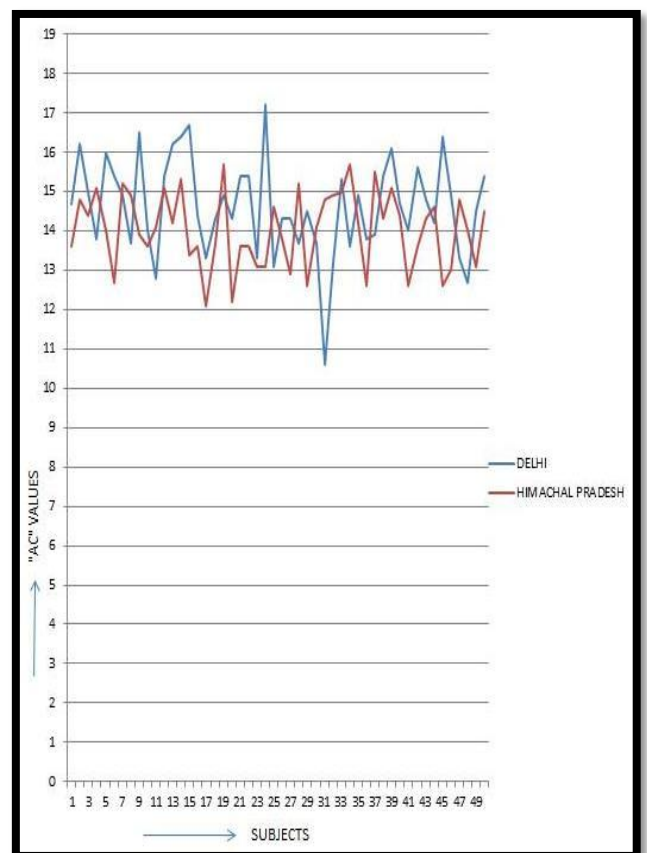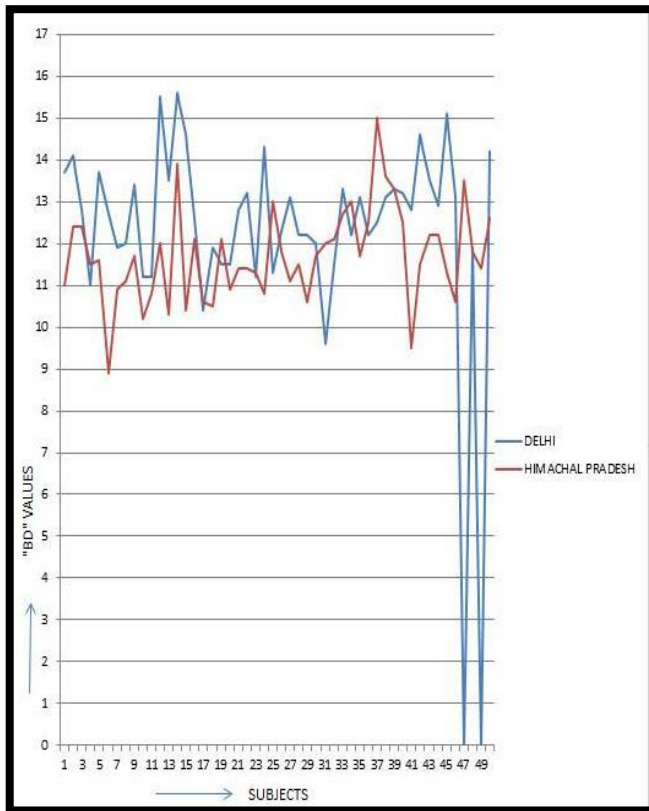
Graph 5: Sie Values (Foot Angle).

Graph 7: CD Values (Maximum width at the heel).

Graph 6: AB Values (Maximum width at the metatarsal).

Graph 8: AC Values (Length of inner tangent from metatarsal to heel i.e; A to C).

Graph 9: BD Values (Length of outer tangent from metatarsal to heel i.e; B to D).
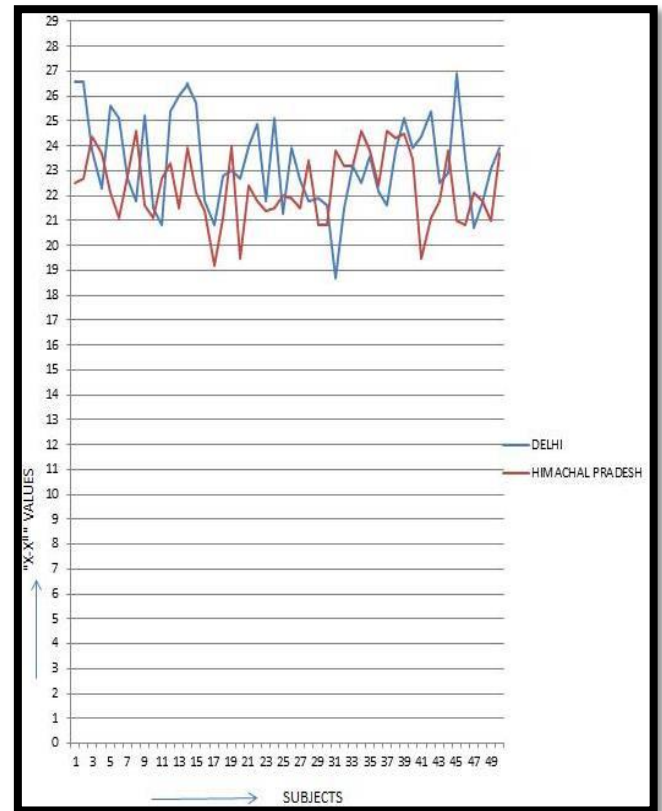
Graph 11: X-X^{II} Values (Distance from pternion to top most point on second toe).
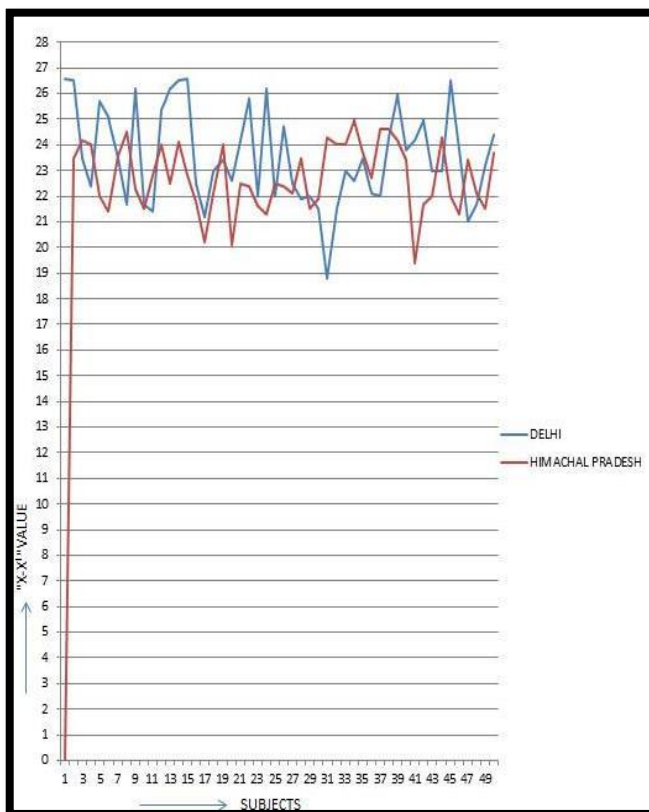
Graph 10: X-X^{I} Values (Distance from pternion to top most point on first toe).
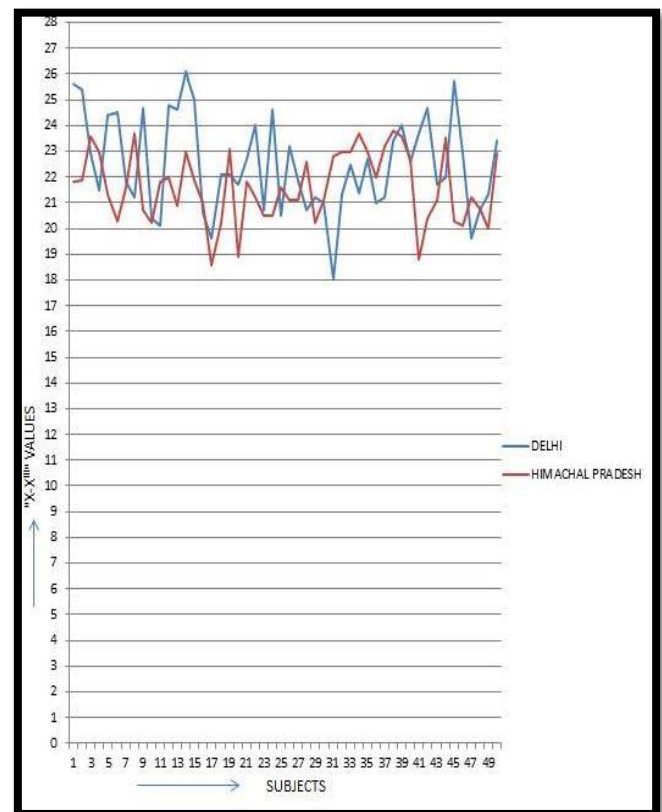
Graph 12: X-X^{III} Values (Distance from pternion to top most point on third toe).
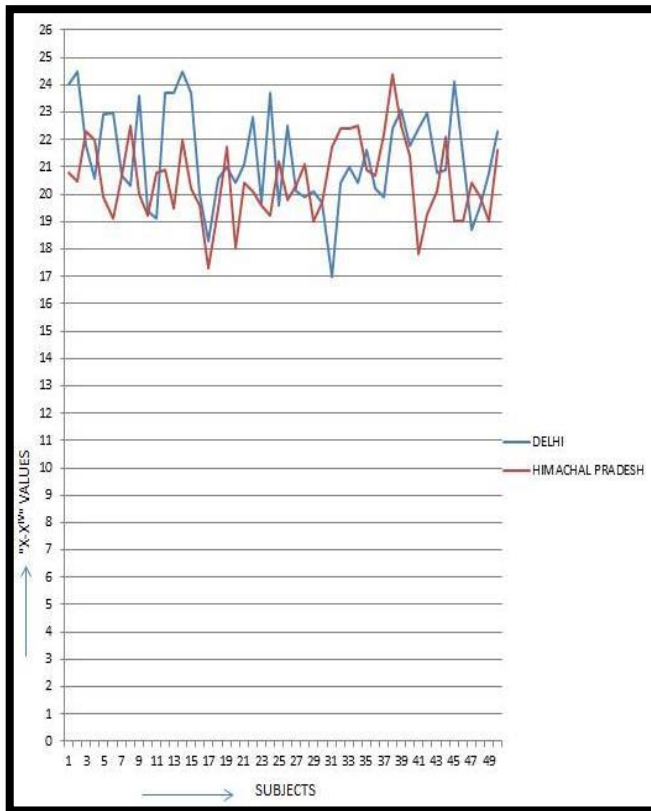
Graph 13: X-X^{IV} Values (Distance from pternion to top most point on fourth toe).
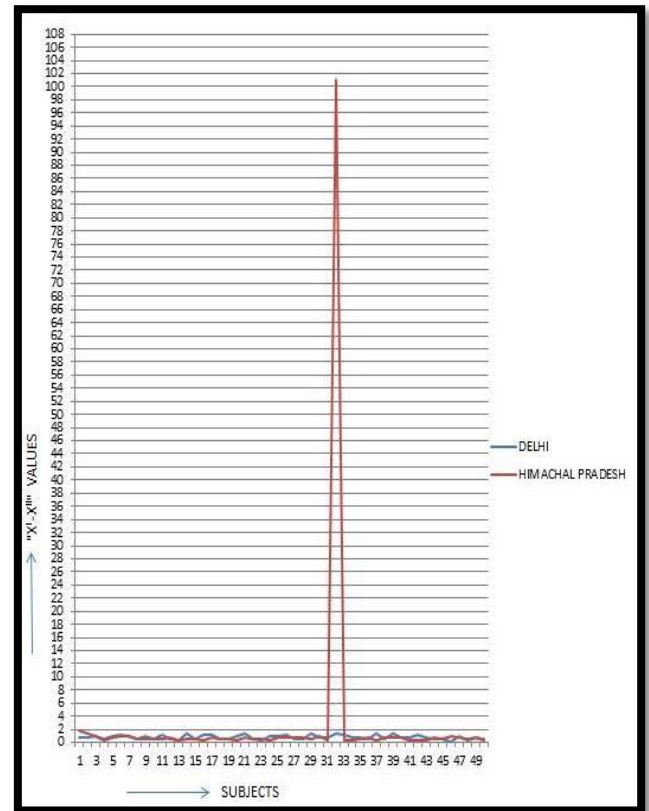
Graph 15: X^{I}-X^{II} Values (Distance between first toe and second toe).
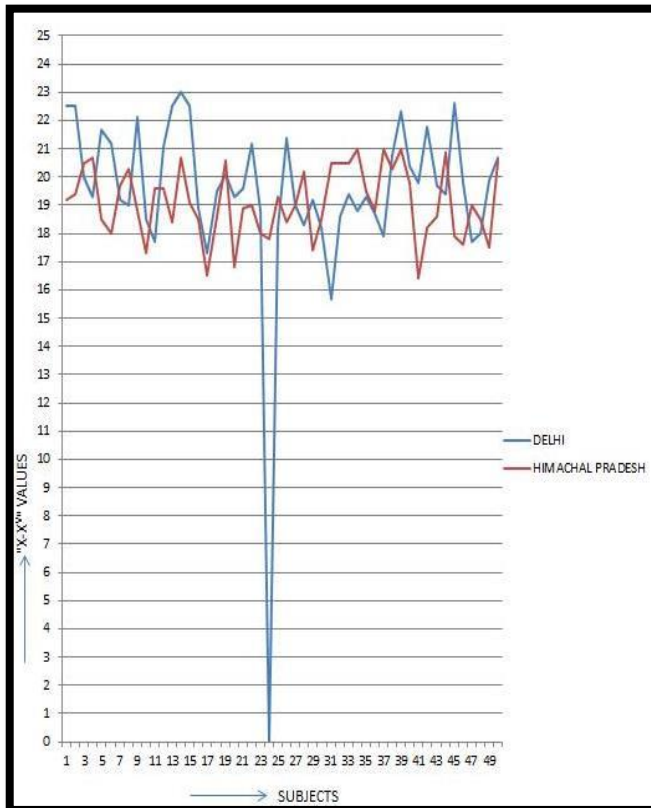
Graph 14: X-X^{V} Values (Distance from pternion to top most point on fifth toe).
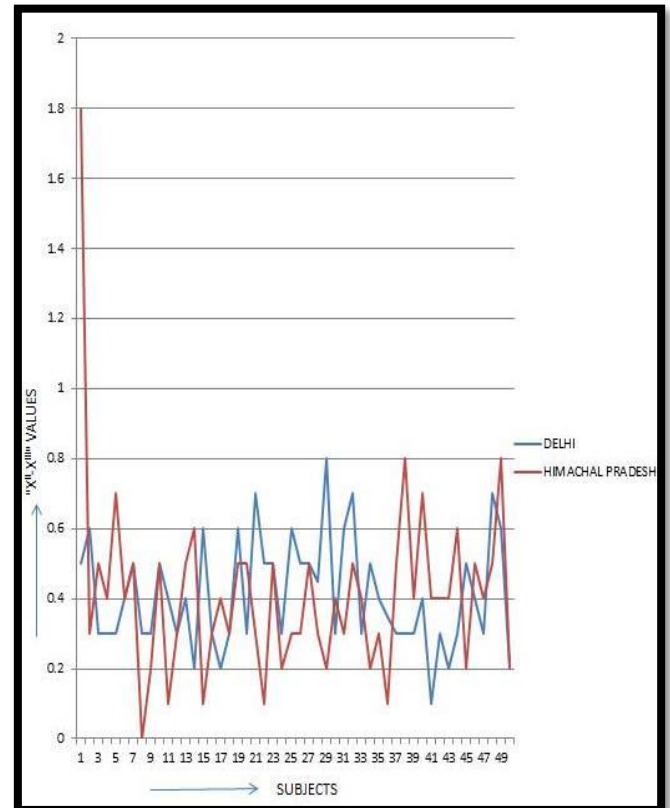
Graph 16: X^{II}-X^{III} Values (Distance between second toe and third toe).
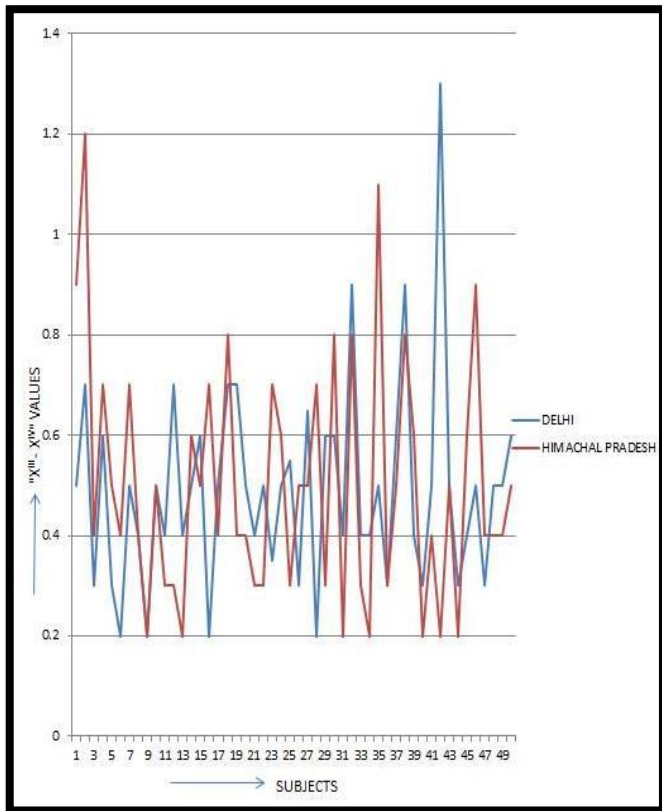
Graph 17: X^{III}-X^{IV} Values (Distance between third toe and fourth toe).
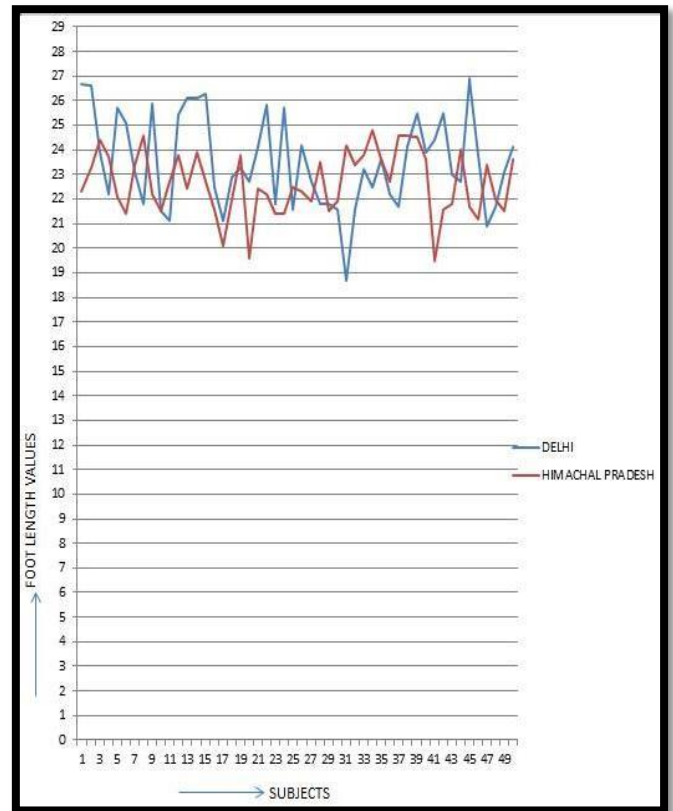
Graph 19: Foot Length Values (Distance between acropodian and the pternion).
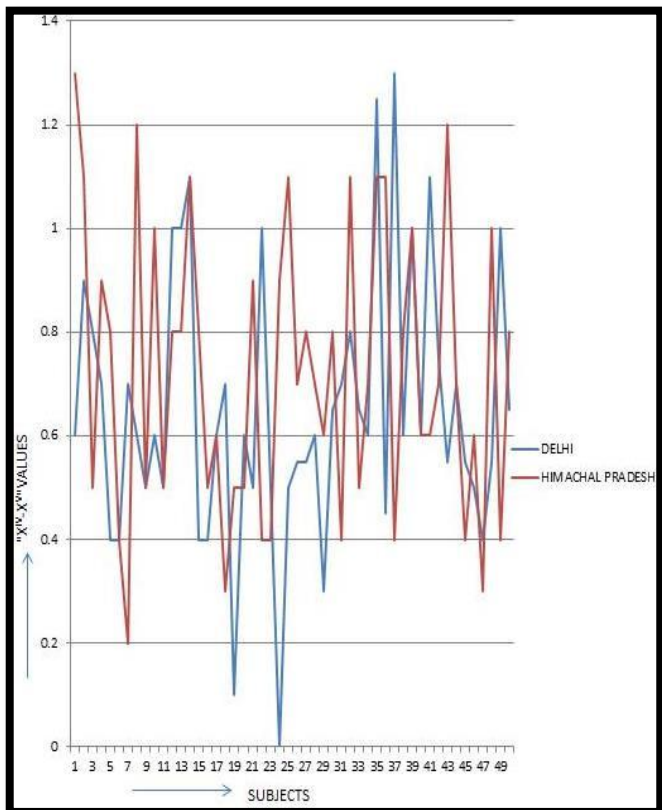
Graph 18: X^{IV}-X^{V} Values (Distance between fourth toe and fifth toe).
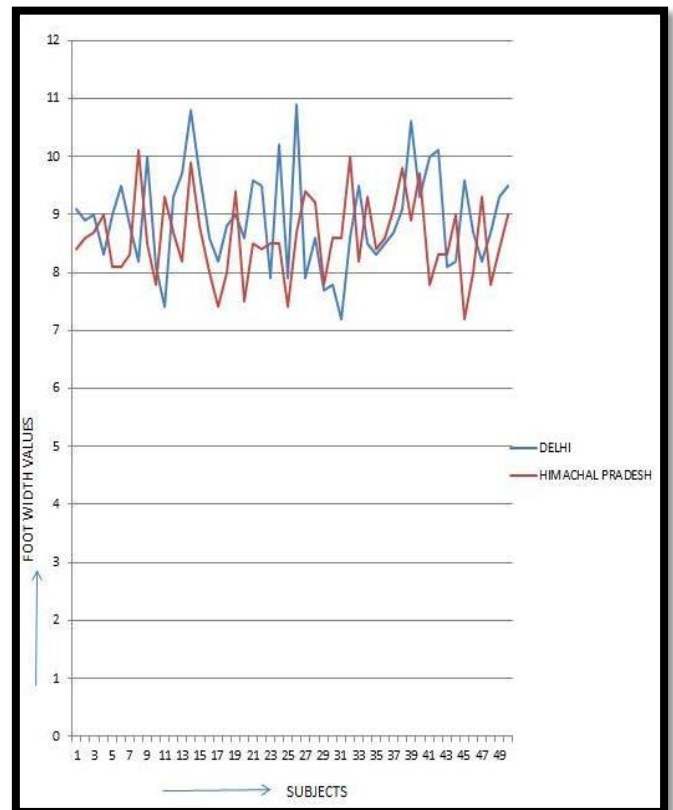
Graph 20: Foot Width Values (Distance between metatarsal fibula and metatarsal tibia).
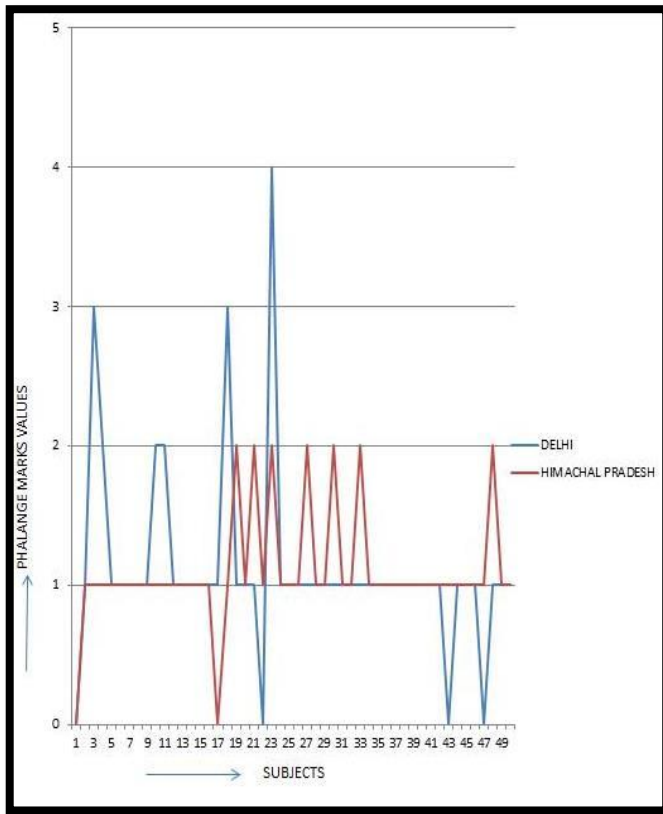
Graph 21: Phalange Marks Values (The ridges connecting toes with the mid foot).
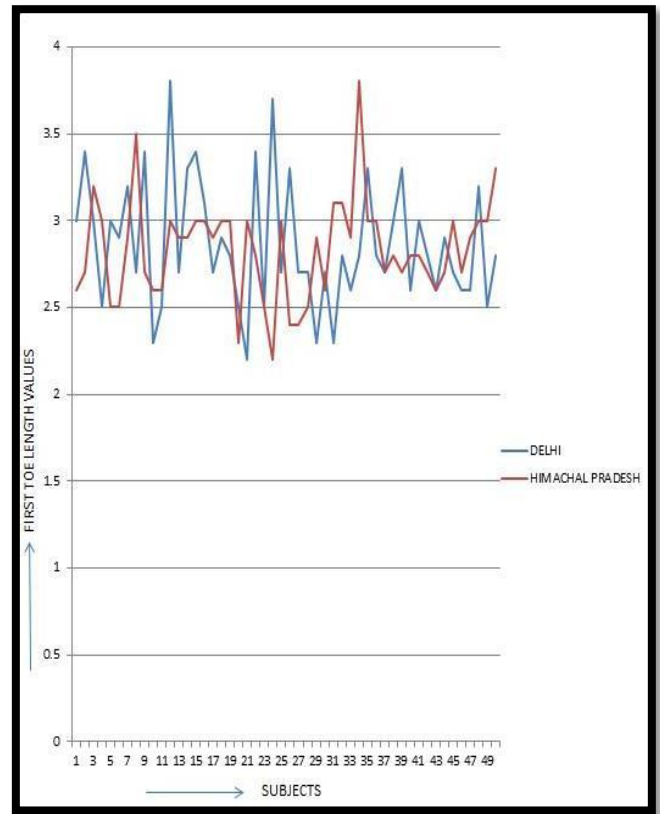
Graph 23: First Toe Length Values (Maximum length of first toe).

Graph 22: Humps Values (Raised area on the mid foot).

Graph 24: First Toe Width Values (Maximum width of first toe).
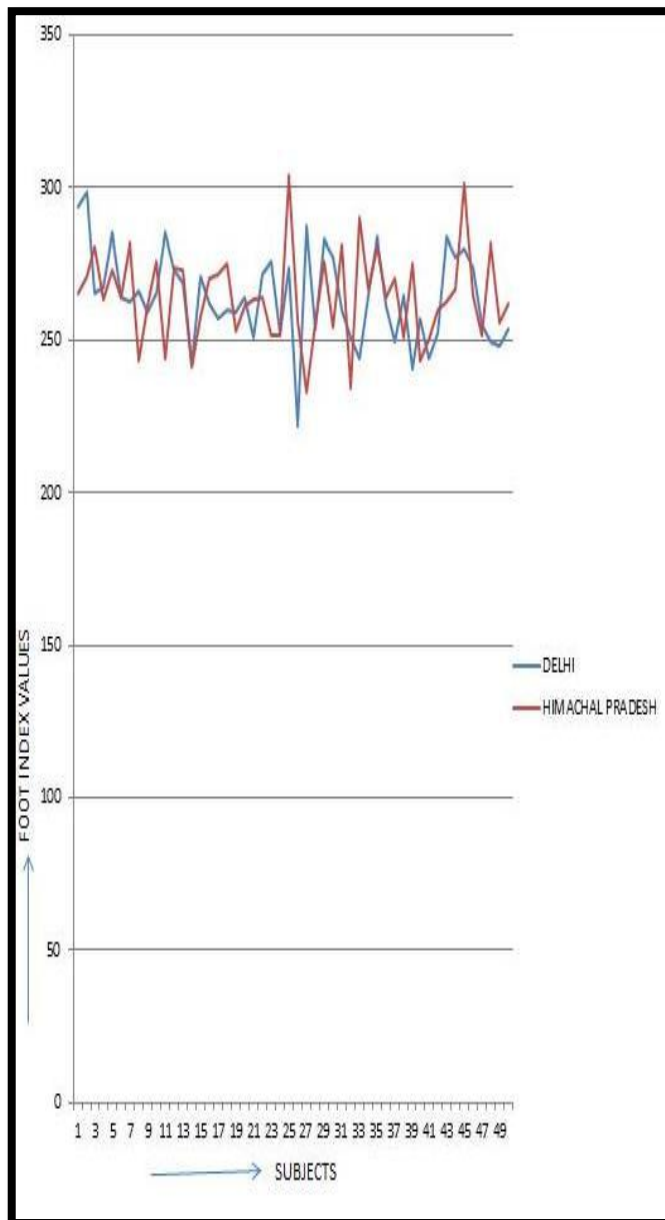
Graph 25: Foot Index Values (Percentage of length v/s width of the foot).

Table 2: Average, Standard Deviation, Minimum and Maximum values of the samples of the two populations.

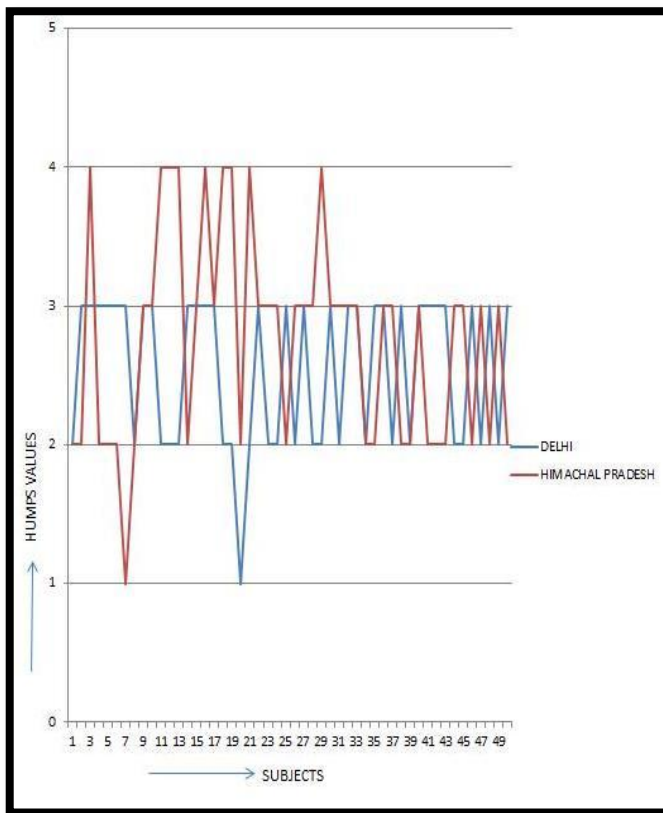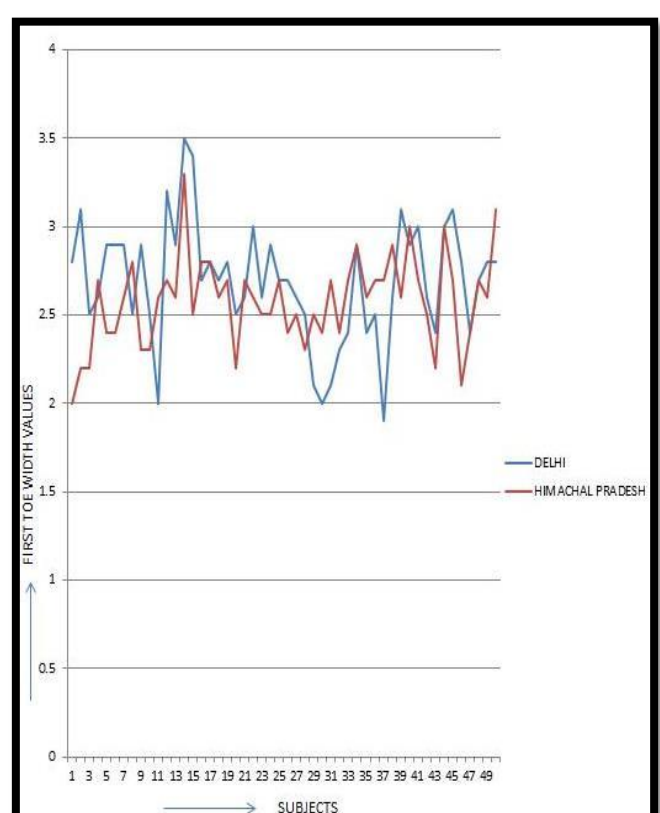| S. No.	PARAMETERS	AVERAGE	SD	MINIMUM	MAXIMUM
1	ALPHA	26.802587	68.29406	0	293.4065934
2	BETA	27.99708241	69.42837	0.3	298.8764045
3	GAAMA	27.04735393	66.41287	0.3	280.4597701
4	THEETA	26.1532254	64.5689	0.3	267.4698795
5	SIE	27.23532457	68.00549	0.3	285.5555556
6	AB	26.03775179	64.30269	0.2	264.2105263
7	CD	26.46649096	66.31791	0.2	281.9277108
8	AC	25.47243797	62.01455	0	265.8536585
9	BD	26.08363971	63.25498	0.2	261.1764706
10	$X-X^1$	25.75228205	65.91539	0.5	275.6410256
11	$X-X^2$	25.59753615	64.63935	0.1	285.1351351
12	$X-X^3$	27.17129681	66.47767	0.3	273.5632184
13	$X-X^4$	26.79509052	65.98124	0.2	273.1707317
14	$X-X^5$	25.62752525	58.59596	0.2	241.6666667
15	X^1-X^1	26.58089269	64.34433	0.1	271.1340206
16	X^2-X^3	25.71649709	64.70789	0.2	270
17	X^3-X^4	24.91995921	64.47821	0	271.6216216
18	X^4-X^5	25.99147727	65.15101	0.3	275
19	FOOT LENGTH	25.77438682	62.2345	0.1	258.8888889
20	FOOT BREADTH	25.07146318	64.0158	0.3	263.9534884
21	PHALANGE MARKS	25.6678462	62.57035	0.3	263.5294118
22	HUMPS	26.49264568	65.20234	0	271.5789474
23	FIRST TOE LENGTH	25.50981478	64.29289	0.25	275.9493671
24	FIRST TOE BREADTH	24.73673407	61.41037	0	251.9607843
25	FOOT INDEX	27.29908953	70.50094	0.3	304.0540541

IV.   RESULT AND DISCUSSION

Using various parameters mentioned above in Table-1, anthropometric measuremnts on the samples were done and mathematical formulas were applied. The miniumum, maximum, average and standard deviation values were calculated as seen in Table-2.

It was found that the minimum values ranged from 0 to 0.5. The maximum values ranged from 241.6666667 to 304.0540541. The average values ranged from 24.73673407 to 27.99708241. The standard deviation values ranged from 58.59596 to 70.50094.

For undergoing statistical evaluation, firstly the variances of the two populations were determined using F-Test and their individual mean and variances are tabulated as seen in Table- 3 and Table-4.

Table 3: Mean and Variance of the Himachal Pradesh samples.

S. No.	PARAMETERS	MEAN	VARIANCE
1	ALPHA	8.13265	37.6956
2	BETA	15.2449	41.1888
3	GAAMA	24.7755	32.3027
4	THEETA	32.3061	22.4252
5	SIE	30.6939	86.5085
6	AB	8.25102	0.39713
7	CD	4.56939	0.20134
8	AC	14.0449	0.92836
9	BD	22.6592	1.71205
10	X-X1 VALUES	22.7551	1.69211
11	X-X2 VALUES	22.3429	2.02792
12	X-X3 VALUES	21.6184	1.90736
13	X-X4 VALUES	20.5184	2.07486
14	X-X5 VALUES	19.1061	1.60559
15	X1-X2 VALUES	2.66122	205.712
16	X2-X3 VALUES	0.38367	0.03223
17	X3-X4 VALUES	0.49184	0.05535
18	X4-X5 VALUES	0.70816	0.07202
19	FOOT LENGTH	22.6592	1.71205
20	FOOT BREADTH	8.59388	0.48934
21	PHALANGE MARKS	1.12245	0.15136
22	HUMPS	2.77551	0.59439
23	FIRST TOE LENGTH	2.83878	0.08576
24	FIRST TOE BREADTH	2.59184	0.06118
25	FOOT INDEX	264.505	230.465

Table 4: Mean and Variance of the Delhi samples.

S. No.	PARAMETERS	MEAN	VARIANCE
1	ALPHA	5.97959	15.3121
2	BETA	13.102	44.5102
3	GAAMA	21.9796	30.6454
4	THEETA	29.5102	40.5051
5	SIE	32.3673	101.779
6	AB	8.63878	0.64326
7	CD	4.76531	0.38898
8	AC	14.6204	1.56457
9	BD	12.7204	1.59874
10	X-X1 VALUES	23.4959	3.38623
11	X-X2 VALUES	23.2673	3.24891
12	X-X3 VALUES	22.4041	3.31665
13	X-X4 VALUES	21.2816	3.0182
14	X-X5 VALUES	19.4	10.63
15	X1-X2 VALUES	0.81122	0.10138
16	X2-X3 VALUES	0.40816	0.02462
17	X3-X4 VALUES	0.49082	0.0407
18	X4-X5 VALUES	0.65	0.06948
19	FOOT LENGTH	23.4184	3.38445
20	FOOT BREADTH	8.9102	0.74719
21	PHALANGE MARKS	1.14286	0.45833
22	HUMPS	2.55102	0.29422
23	FIRST TOE LENGTH	2.86122	0.13576
24	FIRST TOE BREADTH	2.68776	0.11776
25	FOOT INDEX	263.632	216.107

After calculating the mean and variance of the two populations. F-Test was applied to check the variances of the parameters and determining whether the variances are equal or unequal as seen in Table-5.

Table 5: F-test for determining variances of the parameters.

S. No.	PARAMETERS	F-STAT	F-CRITICAL	P-VALUE (one-tailed)	VARIANCES
1	ALPHA	0.4062	0.61905	0.00113	EQUAL
2	BETA	1.08064	1.61537	0.39465	EQUAL
3	GAAMA	0.94869	0.61905	0.42799	UNEQUAL
4	THEETA	1.80623	1.61537	0.02154	UNEQUAL
5	SIE	1.17652	1.61537	0.28778	EQUAL
6	AB	1.61975	1.61537	0.04906	UNEQUAL
7	CD	1.932	1.61537	0.01224	UNEQUAL
8	AC	1.68531	1.61537	0.03683	UNEQUAL
9	BD	0.93382	0.61905	0.40674	UNEQUAL
10	X-X1 VALUES	2.00119	1.61537	0.00895	UNEQUAL
11	X-X2 VALUES	1.60209	1.61537	0.05296	EQUAL
12	X-X3 VALUES	1.73887	1.61537	0.02907	UNEQUAL
13	X-X4 VALUES	1.45465	1.61537	0.09892	EQUAL
14	X-X5 VALUES	6.62063	1.61537	0.01264	UNEQUAL
15	X1-X2 VALUES	0.00049	0.61905	0	EQUAL
16	X2-X3 VALUES	0.76392	0.61905	0.17706	UNEQUAL
17	X3-X4 VALUES	0.73525	0.61905	0.14508	UNEQUAL
18	X4-X5 VALUES	0.96478	0.61905	0.45084	UNEQUAL
19	FOOT LENGTH	1.97684	1.61537	0.01	UNEQUAL
20	FOOT BREADTH	1.52693	1.61537	0.07308	EQUAL
21	PHALANGE MARKS	3.02809	1.61537	9.7E-05	UNEQUAL
22	HUMPS	0.49499	0.61905	0.00822	EQUAL
23	FIRST TOE LENGTH	1.58304	1.61537	0.0575	EQUAL
24	FIRST TOE BREADTH	1.92481	1.61537	0.01264	UNEQUAL
25	FOOT INDEX	0.9377	0.61905	0.41229	UNEQUAL

If critical value is greater than statistical value then formula applied would be for equal variance and if critical value is greater thaan statistical value then formula applied would be for unequal variance.

On the basis of results from F-test, appropriate formulas for equal variance for T-test and unequal variance for T-testwere applied to the two populations as seen in Table-6 and Table- 7.

Table 6: Parameters with equal variances.

S. No.	PARAMETERS	t-stat	P (one-tailed)	t-critical (one-tailed)	P (two-tailed)	t-critical (two-tailed)
1	ALPHA	-2.07007047	0.020565523	1.66088144	0.041131047	1.984984312
2	BETA	-1.62032985	0.0542209	1.66088144	0.1084418	1.984984312
3	SIE	0.853699773	0.197698267	1.66088144	0.395396533	1.984984312
4	X-X2	2.817174076	0.00294102	1.66088144	0.00588204	1.984984312
5	X-X4	2.367467979	0.009958106	1.66088144	0.019916212	1.984984312
6	X1-X2	-0.90267729	0.184478278	1.66088144	0.368956556	1.984984312
7	FOOT BREADTH	1.991281758	0.024645944	1.66088144	0.049291889	1.984984312
8	HUMPS	-1.66701750	0.049385133	1.66088144	0.098770266	1.984984312
9	FIRST TOE LENGTH	0.333883104	0.369598003	1.66088144	0.739196007	1.984984312

Table 7: Parameters with unequal variances.

S. No.	PARAMETERS	t-stat	P (one-tailed)	t-critical (one-tailed)	P (two-tailed)	t-critical (two-tailed)
1	GAAMA	-2.46678	0.0077	1.66088	0.01541	1.98498
2	THEETA	-2.46713	0.00777	1.66216	0.01553	1.98698
3	AB	2.66108	0.0046	1.66177	0.00921	1.98638
4	CD	1.78497	0.03888	1.66256	0.07775	1.98761
5	AC	2.5515	0.00621	1.66196	0.01241	1.98667
6	BD	1.11795	0.13392	1.6694	0.26784	1.99834
7	X-X1	2.30116	0.0119	1.66277	0.0238	1.98793
8	X-X3	2.40636	0.00909	1.66216	0.01818	1.98698
9	X-X5	0.5881	0.2793	1.6698	0.5586	1.99897
10	X2-X3	0.719	0.23696	1.66123	0.47393	1.98552
11	X3-X4	-0.02305	0.49083	1.66123	0.98166	1.98552
12	X4-X5	-1.08237	0.1409	1.66088	0.2818	1.98498
13	FOOT LENGTH	2.35401	0.01041	1.66256	0.02082	1.98761
14	PHALANGE MARKS	0.18296	0.42766	1.66488	0.85531	1.99125
15	FIRST TOE BREADTH	1.58723	0.05804	1.66256	0.11609	1.98761
16	FOOT INDEX	-0.2893	0.38649	1.66088	0.77297	1.98498

FOR EQUAL VARIANCES

From Table-6, it can be observed that parameters X-XII, X-XIV, ALPHA and FOOT BREADTH gave the most significant results in test for equal variances with values 0.00294-0.00588, 0.00995-0.01991, 0.02056-0.04113 and 0.02464-0.04929. Which is also illustracted in Graphs-11, 17, 1 and 20.

The most non-significant result in test for equal variances was produced by parameters: XI-XII and FIRST TOE LENGTH with values 0.18447-0.36895 and 0.36959-0.739189. Which can also be observed in Graphs-15 and 23.

Somewhat significant results (partially significant) were observed in paramters BETA, SIE and HUMPS with values0.05422-0.10844, 0.19769-0.39539 and 0.0493-0.09877.As illustrated in Graphs-2,5 and 22.

FOR UNEQUAL VARIANCES

From Table-7, it can be observed that, the most significant results in test for unequal variances were produced by parameters AB, GAMMA, THEETA, X-XIII, FOOT LENGTH, X-XI. That can also be observed in Graphs-6, 3, 4,12, 19 and 10. The values obtained were 0.0046-0.00921, 0.0077-0.01541, 0.0077-0.01553, 0.00909-0.0181, 0.01041-0.0208,0.0119-0.0238.

The most insignificant result were observed in parameters BD, X-XV, XII-XIII, XIII-XIV, XIV-XV, PHALANGE MARKS and FOOT INDEX with values 0.1339-0.2678, 0.2793-0.5586, 0.2369-0.4739, 0.4908-0.9816, 0.1409-0.2818, 0.42766-0.85531 and 0.3864-0.7729. As illustrated by Graphs-9, 14, 16, 17, 18, 21 and 25.

Somewhat significant results (partially significant) were observed in parameters: AC, CD and FIRST TOE BREADTH with values 0.0062-0.0124, 0.0388-0.077 and 0.0580-0.11609. Also illusteated by Graphs-8, 7 and 24.

In the present study it was observed that 11 parameters gave significant results and 14 parameters gave non-signinficant results in study conducted on 100 samples with 25 parameters.

In the previous study,T. Nataraj Moorthy and Siti Fatimah Binti Sulaiman stated thatbare footprints does not reflect the actual foot size but represent the plantar portion of the foot. Further, this study supports the present study since it stated that humps indicates that people from different regions and races bear different morphological features of feet and foot prints. Also,

another study by T. Nataraj Moorthy showed that the footprints of Indian Tamils are different from other Indian populations. It is well known that people from different regions of a country and world have different morphological features depending on their geographical distribution and racial characteristics. Sween Walia in her research on similar topic of racial difference in Haryanvi Jat Population concluded that foot length in both sexes was higher in comparison to the studies done in Mauritius, Turkey and South India. Also, the foot length was statistically higher as compared to studies done in Sri Lanka, North India and Iran.

CONCLUSION

From this study, it was concluded that footprints can also reveal significant regional differences. In the present study two populations were taken: Himachal Pradesh and Delhi and with the help of graphs and tables it was concluded that there were differences in the measurents of footprints of the two populations. Further it was also found through statistical analysis that there were significant differences in the two populations and if any footprint is found at any scene of crime and if there is question of the identity of the print between the two, then through comparative study by implying the parameters used in this study, it can be suggested that the footprint belongs to a particular population. In some cases, to establish the identity of the person sometimes only a small portion of the sole print of the foot may be sufficient. Thus, from the aspect of human friendliness a promising method to recognize individuals is footprints.

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