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ORIGINAL ARTICLE

A Forensic Study of Ethnicity and Sex Differences in Fingerprint Patterns in a Malaysian Sub-population

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ABSTRAK

Cap jari merupakan sejenis bahan bukti yang paling biasa dijumpai di tempat kejadian. Disebabkan keunikan corak cap jari, ia berguna untuk pengenalpastian suspek. Pada kebiasaannya, sumbangan cap jari yang dipertikaikan agak terhad disebabkan oleh kekaburan minutia atau ketiadaan suspek yang berpotensi. Walau bagaimanapun, ia masih berguna jika etnisiti atau jantina cap jari yang dipertikaikan dapat ditaabirkan untuk mengecilkan skop pencarian suspek. Oleh demikian, kajian ini bertujuan memeriksa perbezaan jantina dan etnisiti dalam corak cap jari di kalangan tiga kumpulan etnik utama di Malaysia, iaitu Melayu, Cina dan India. Sejumlah 2000 cap jari telah dikutip daripada sepuluh jari bagi 200 subjek Malaysia (99 lelaki dan 101 perempuan). Setiap tiga kumpulan etnik itu diwakili oleh sekurang-kurangnya 60 subjek. Statistik perihalan dan ujian hipotesis telah dijalankan untuk menilai variasi jantina dan etnisiti dalam corak cap jari. Tambahan pula, analisis penghubungan mudah juga dijalankan untuk menyokong statistik perihalan dan statistik pentakbiran. Dengan mempertimbangkan corak cap jari semua sepuluh jari, membulat merupakan corak yang paling kerap di Melayu (23.0%) dan India (23.2%); sementara Cina (13.9%) menunjukkan frekuenksi sedikit tinggi dalam pusaran berbanding Melayu (9.6%) dan India (10.3%). Taburan relatif corak cap jari lelaki adalah serupa dengan taburan relatif corak jari perempuan. Sebagai kesimpulannya, corak cap jari mungkin boleh digunakan untuk menaabir etnisiti suspek daripada jantina suspek dalam konteks Malaysia.

Kata kunci: cap jari, Malaysia, ujian khi-kuasa dua

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ABSTRACT

Fingerprint is one of the most common evidence found at a crime scene. Owing to the uniqueness of fingerprint, it is useful for suspect identification. Typically, the questioned fingerprint is of limited contribution due to blurriness of the minutia or absence of potential suspect. However, it is still useful if the ethnicity or sex of the questioned fingerprint could be inferred to narrow down the scope of searching of suspect. Therefore, this study aims to examine sexual and ethnic differences in fingerprint patterns among the three major ethnic groups in Malaysia, i.e. Malays, Chinese and Indians. In total, 2000 plain fingerprints were collected from all the ten fingers of 200 Malaysians (i.e. 99 males and 101 females). Each of the three ethnic groups was represented by at least 60 subjects. Descriptive statistics and hypothesis test were performed to assess the sexual and ethnic variability of fingerprint patterns. In addition, simple correspondence analysis was also conducted to support the descriptive and inferential statistics. By considering fingerprint patterns in all the ten fingers, loop was the most frequent pattern in Malays (23.0%) and Indians (23.2%), while Chinese (13.9%) showed slightly higher frequency of whorl than Malays (9.6%) and Indians (10.3%). The relative distribution of fingerprint patterns of male was similar to that of female. In conclusion, fingerprint patterns could be used to infer the ethnicity rather than the sex of a suspect in the Malaysian context.

Keywords: Chi-Square test, fingerprints, Malaysia

INTRODUCTION

Fingerprint is one of the most common evidence found at a crime scene. It can be deposited on various types of surfaces or substrates (Meuwly 2009). Owing to the uniqueness of fingerprint, it is very useful in forensic investigation for suspect identification by comparing the questioned fingerprint recovered from a crime scene with a suspect's fingerprint. Matching is achieved if both the fingerprints show similarities in minutia types and locations. Therefore, reliability of the matching is heavily affected by the quality of the questioned fingerprint (Fieldhouse 2011; Ulery et al. 2011). In practice, fingerprint collected from a crime scene may be blurred, degraded or partial. In such circumstances, the comparison analysis may not accurately identify the right suspect (Neumann 2012). However, the fingerprint pattern, i.e. loop, arch and whorl could be inferred with high confidence even the fingerprint is partial.

Typically, fingerprint features can be divided into three levels i.e. (i) level-1 (pattern); (ii) level-2 (minutiae points); and (iii) level-3 (e.g. pores and ridge contours) (Kryszczuk et al. 2004). Among these features, level-2 features are the most studied ones in the forensic literature. Numerous works have been carried out on sex determination from fingerprint ridge density by using a variety of populations (Adamu et al. 2018; Adamu & Taura 2017; Ahmed & Osman 2016; Dhall & Kapoor 2016; Gutierrez-Redomero & Alonso-Rodriguez 2013; Nayak et al. 2010; Taduran et al. 2016). In general, most of the works indicated that male tends to show less number of ridge counts than the female. However, accurate calculation of ridge density is much easier to be performed in a rolled than a plain print. Unfortunately, in practice, very unlikely a rolled print would be found at a crime scene.

On the other hand, level-3 features concerning the fine details of fingerprint, e.g. pores and ridge contours, are of limited use in real forensic investigation. As mentioned above, quality of the fingerprint collected from a crime scene can be very low and thus it is impractical to explore the level-3 features in forensic investigation except for biometric security technology. Moreover, Gupta et al. (2008) found that the reproducibility of friction ridge pore detail in identifying a person is too low for a reliable personal identification.

In contrast, level-1 features referring to the fingerprint patterns have been studied mainly for estimating frequency of occurrence in a population but not on discriminating sex or ethnicity (Kapoor & Badiye 2015; Nithin et al. 2009; Wijerathne et al. 2013). Additionally, a few studies have demonstrated the use of fingerprint patterns in discriminating populations. For instance, Swofford (2005) found that Asians' fingerprints tended to be dominated by whorls whereas Blacks had more loops and arches in their fingerprints. Moreover, the researcher concluded that there was a linkage of fingerprint pattern types, ethnicity, and the finger on which they occur. On the other hand, Stambouli et al. (2015) showed that males tended to show whorls and radial loops than female; and the difference was found to be significant. Recently, Baryah and Krishan (2020) explored the role of fingerprint patterns in discriminating sex and ethnicity by using a North Indian population.

Despite that, to the best of our knowledge, there are very limited works studying fingerprint patterns for forensic investigation using the Malaysian population. Malaysia is a multi-racial country comprising of Malays, Chinese and Indians as well as a variety of minority ethnic groups (Jabatan Perangkaan Malaysia 2020). Recently, Gan et al. (2018) reported the distribution of fingerprint patterns by ethnicity and sex of 192 Malaysians. The authors concluded that Malays and Chinese shared similar distributional patterns which was different from that deriving from Indians. Chi-square test indicated that the distribution of fingerprint patterns in all ten fingers among Chinese, Malays and Indians were different (p-value <0.01). Despite the sample size approaching 200 Malaysians, the Chinese and Indians took up only around 13% and 3.6% of the total subjects, respectively. Moreover, the proportion of male and female and compliance with the two statistical assumptions of Chi-square test were not explicitly explained in the manuscript. Hence, the findings

Table 1: Classification systems of fingerprint patterns and the respective codes

Type	Class (Code)		
3-Class	Arch (1)	Loop (2)	Whorl (3)
9-class	Plain arch (1)	Left/Ulnar loop (3)	Double loop (5)
	Tented arch (2)	Right/Radial loop (4)	Plain whorl (6)
			Central pocket loop whorl (7)
			Accidental whorl (8)
			Unknown (9)

presented by Gan et al. (2018) might be inaccurate and unreliable.

Therefore, this study aims to explore the use of fingerprint patterns in predicting ethnicity and sex in a Malaysian subpopulation. The impacts of finger and type of fingerprint-classification system i.e. (i) three-classes of fingerprint (loops, whorls and arches); and (ii) nine-classes of fingerprint (arch, tented arch, right loop, left loop, double loop, plain whorl, central pocket loop whorl, accidental whorl and unknown) were also explored in this study. For a comprehensive evaluation, correspondence analysis technique has been employed herein in addition to the descriptive and inferential statistics.

MATERIALS AND METHODS

Sample Collection

A total of 2000 fingerprints were collected from 200 healthy Malaysian subjects, fully informed and consented. The subjects comprising Indians, Malays and Chinese were mainly students that studied at Universiti Kebangsaan Malaysia (UKM), Malaysia. The plain prints were collected after the fingers have been cleaned with alcohol swab. In general, each ethnic group was represented by at least 60 subjects; and comprised of at least 30 female and male subjects, respectively.

Fingerprint Data

Images of the fingerprints were captured using a digital microscope (Dino-Lite) and saved as JPEG format in a laptop. Table 1 shows the codes defining the ten fingers. Then, each of the 2000 fingerprints was classified according to two different classification systems (Table 2).

Statistical Analysis

The fingerprint data were analysed using the R software (R Core Team 2019). Chi-square test was performed to evaluate relationship between

Table 2: Descriptions of codes defining the ten fingers

Hand	Right	Left
Thumb	R1	L1
Index	R2	L2
Middle	R3	L3
Ring	R4	L4
Little	R5	L5

Table 3: Frequency of occurrence (%) by ethnicity and sex in three primary fingerprint patterns (n = 2000)

Ethnicity	Sex	Frequency of occurrence (%)		
		Arch	Loop	Whorl
Chinese	Female	0.2	8.7	7.7
	Male	0.0	10.3	6.2
Indians	Female	0.3	11.6	5.7
	Male	0.3	11.6	4.6
Malays	Female	0.1	11.0	5.5
	Male	0.4	12.0	4.2
Grand total	Female	0.6	31.3	18.9
	Male	0.7	33.9	15.0
	Chinese	0.2	19.0	13.9
	Indians	0.6	23.2	10.3
	Malays	0.5	23.0	9.7
	Malaysian	1.3	65.2	33.9

ethnicity/sex and fingerprint pattern; and a p-value less than 0.05 was considered to be statistically significant. Simple correspondence analysis (CA) was also performed to illustrate spatial relationship between fingerprint pattern and ethnicity/sex in a graphical approach, i.e. CA plot.

RESULTS

Descriptive Statistics

Table 3 summaries the frequency of occurrence of three major fingerprint patterns by ethnicity and sex in a particular ethnic group, respectively. The grand total of frequency for the two sexes, three ethnic groups and all the 200 Malaysian subjects are also presented in Table 3. Firstly, by referring to the grand total of Malaysian, loop (65.2%) appeared to be the most frequently occurring fingerprint pattern, followed by whorl (33.8%); and arch (1.3%) being the rarest one.

When the grand total of Malaysian was split by ethnicity, again, the three ethnic groups were dominated by loops followed by whorls and the least occurred pattern was arches. However, arch and loop patterns were found to occur more often in Indians and Malays than in Chinese. On the contrary, whorl was more common in Chinese (13.9%) than in Indians (10.3%) or Malays (9.6%). In general, both the Indians and Malays demonstrated highly similar distributional variations in the three fingerprint patterns; and the two ethnic groups were dissimilar with the Chinese.

The frequency distribution of the three primary fingerprint patterns in the three ethnic groups by fingers are shown in Figure 1. In general, all the fingers showed similar frequency distribution of the fingerprint patterns,

Figure 1: Distributional variations of the three fingerprint patterns [arch (1), loop (2), whorl (3)] in the three primary ethnic groups [Chinese (pink), Indians (blue), Malays (green)]

i.e. loops were more frequent than whorls, except for ring fingers that had more whorls than loops. Meanwhile, ethnic differences were evident in ring and little fingers of both hands; as well as thumb and index fingers of the left hand.

With respect to sexual dimorphism in the three primary fingerprint patterns, males were found to present higher frequency of arch and loop than females. Contrary, females (18.9%) showed more whorls than males (15.0%). Next, the Indian females and males have exactly same frequencies of arch and loop patterns, respectively. On the other hand, frequencies of arch and loop patterns of the Malays females were lower than the Malay males. However, the frequency of whorl was higher in both the Indian and Malay females as compared to the respective males. Meanwhile, it is worth to mention that only the Chinese males showed no arch pattern.

Figure 2 illustrates the frequency distribution of the three primary fingerprint patterns by the three ethnic groups and sex according to ten fingers. Sexual dimorphism in Malays, Indians and Chinese was most evident on the index finger of left and right hands. Other fingers showed varying sexual dimorphism according to the

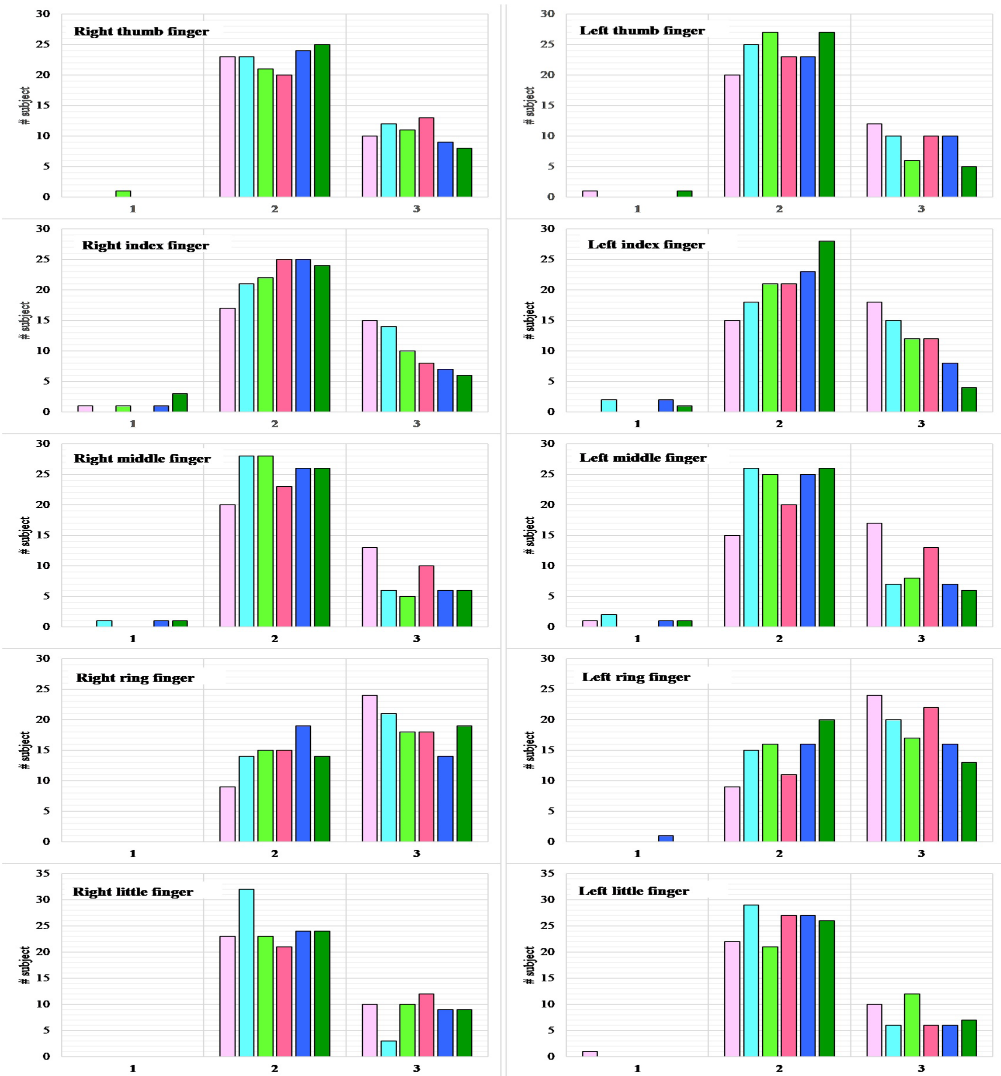

Figure 2: Distributional variations of the three fingerprint patterns [arch (1), loop (2), whorl (3)] by sex and ethnicity [female Chinese (light pink), female Indians (light blue), female Malays (light green), male Chinese (pink), male Indians (blue) and male Malays (green)]

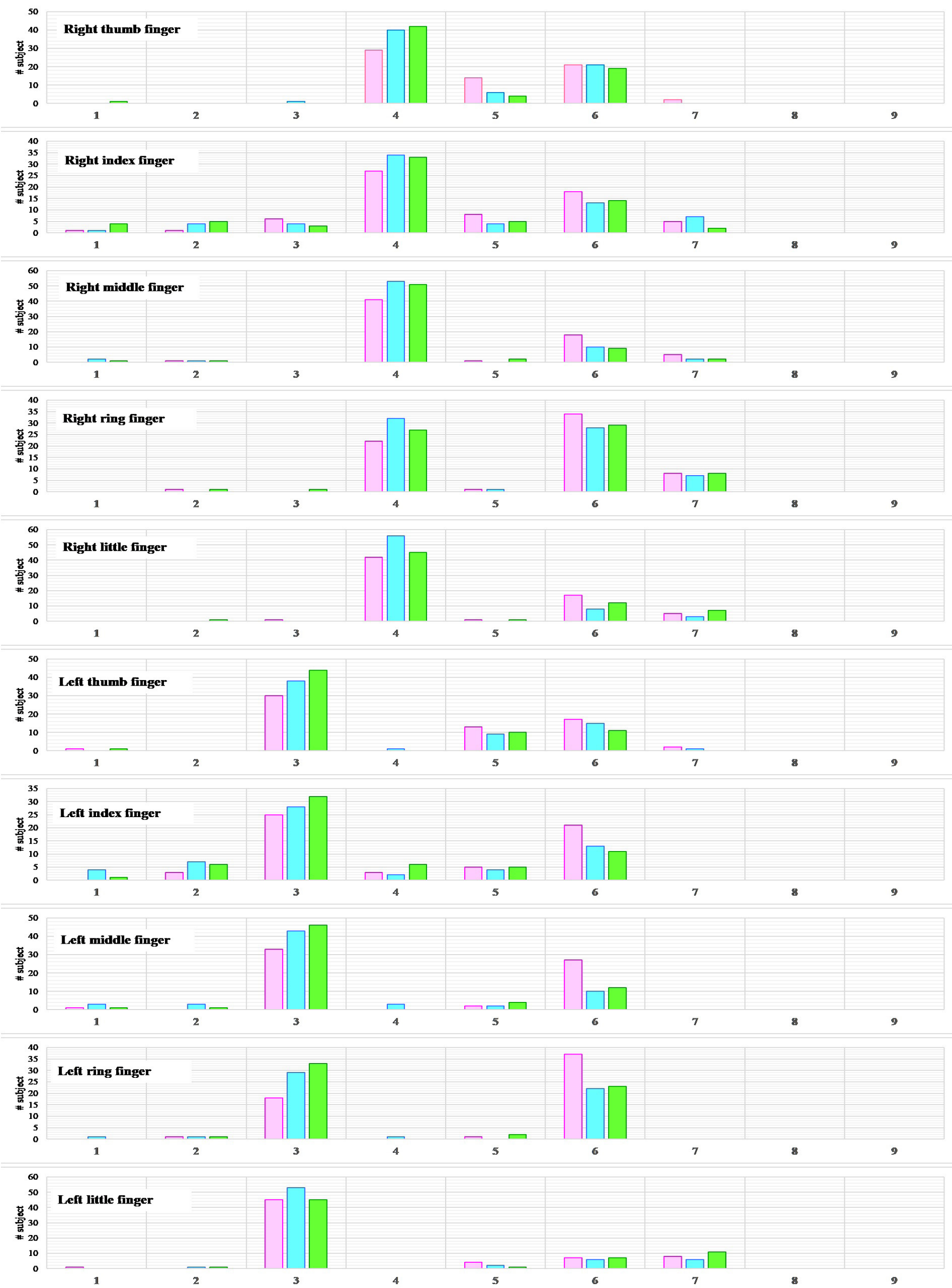

Figure 3: Distributional variations of the nine fingerprint patterns [plain arch (1), tented arch (2), ulnar loop (3), radial loop (4), double loop (5), plain whorl (6), central pocket loop whorl (7), accidental whorl (8), unknown (9)] in the three ethnic groups [Chinese (pink), Indians (blue), Malays (green)]

three ethnic groups.

Figure 3 shows the frequency distribution of the nine fingerprint patterns in the three ethnic groups by fingers; and Figure 4 presents the similar frequency distributions but the three ethnic groups were further split according to sex. It is interesting to see that relative frequencies of pattern types of the right hand were a close resemblance of the corresponding left hand. For instance, the loops were the most commonly occurring pattern on all the fingers of left and right hands except for the ring fingers. Meanwhile the frequencies of the nine fingerprint patterns were the most diverse on the index fingers. In addition, it is worth noting that the left and right hands, could be characterised by the two sub-types of loop. The right hand tends to show radial (right) loop whereas ulnar (left) loop was more often on the left hand. Next, plain whorl is far more prevalent than the other sub-types of whorl.

In brief, descriptive statistics indicate that ethnic difference is much significant than the sexual dimorphism in fingerprint patterns. Nonetheless, some fingers of right hand were found to show sexual dimorphism.

Chi-Square Tests

In order to assess the distributional variations in frequencies of fingerprint patterns, Chi-square tests were performed on the ten fingers. The univariate hypothesis test has been performed using the full fingerprint data to assess ethnicity difference and sexual dimorphism in the 200 Malaysians, respectively. A *p*-value less than 0.05 indicates a significant association between fingerprint patterns and ethnicity/sex.

It is important to note that validity of the chi-square test is affected by two conditions i.e. (i) the expected counts should be 5 or more in at least 80% of the cells; (ii) no cells should have an expected count of less than one (McHugh 2013). As shown in Figure 1 to Figure 4, several of the fingerprint patterns were not represented by any subjects (i.e. observed count of less than one) of which in turn resulted an expected count of less than one. The condition was worsen when the 9-classification system was adopted. Thus, we prepared another reduced data from the full fingerprint data by removing subjects showing arch pattern in at least one of the ten fingers. The purpose was to assess the impact of violating the condition required by a valid Chi-square test.

The results of chi-square test obtained using the full and reduced data are summarised in Table 4 and 5, respectively. From Table 4, we can see that R2 and L3 were the only two fingers that showed significant p-values with both the 3- and 9-classification systems. The former demonstrated the most obvious ethnic difference whereas the latter indicated a significant sexual dimorphism. In other words, inferential statistics revealed that left hand was more suitable than right hand for discriminating the three ethnic groups. In contrast, sexual dimorphism in fingerprint pattern was much evident on right hand. It is worth noting that Chi-square tests performed on the

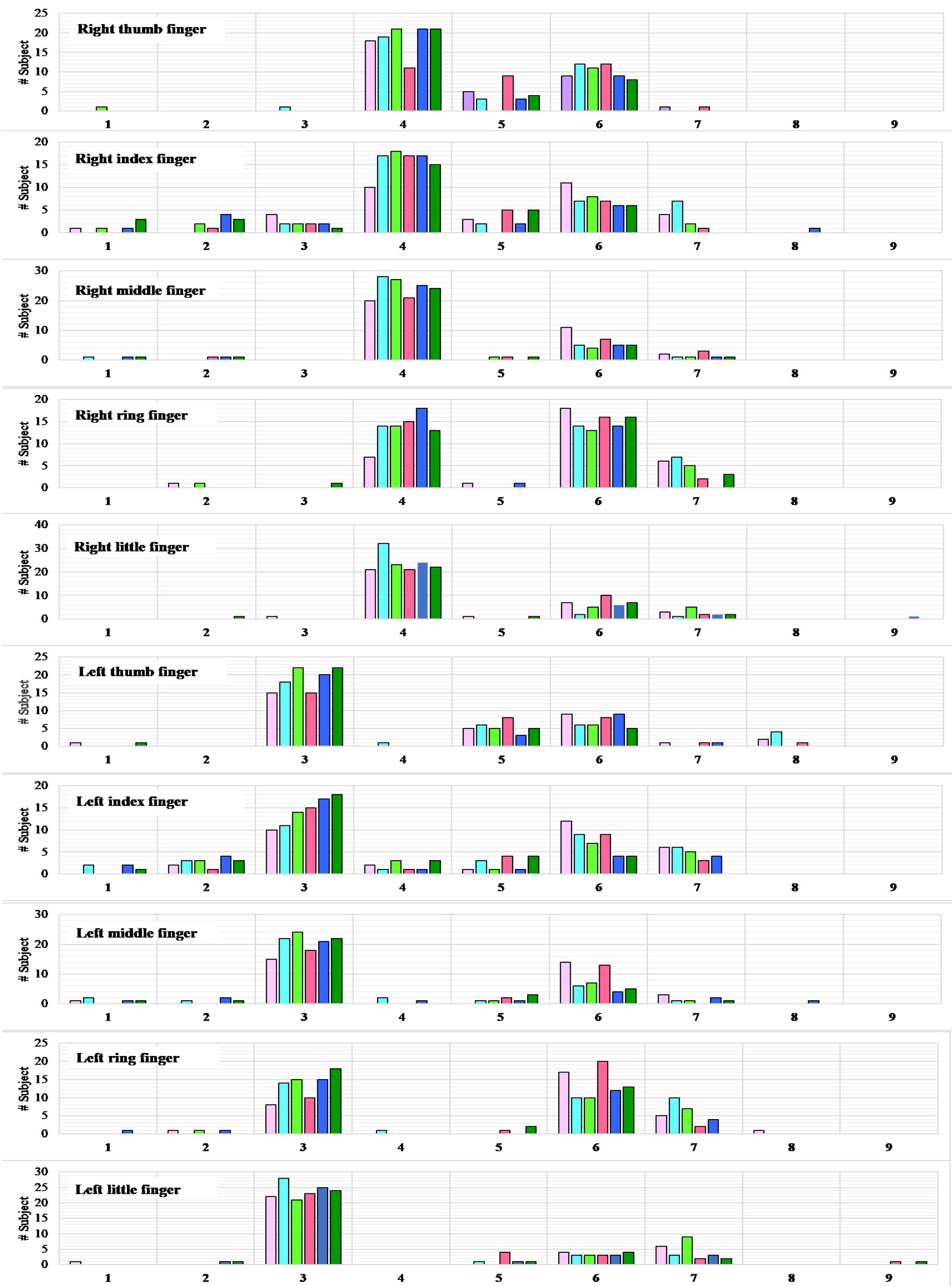

Figure 4: Distributional variations of the nine fingerprint patterns [plain arch (1), tented arch (2), ulnar loop (3), radial loop (4), double loop (5), plain whorl (6), central pocket loop whorl (7), accidental whorl (8), unknown (9)] by sex and ethnicity [female Chinese (light pink), female Indians (light blue), female Malays (light green), male Chinese (pink), male Indians (blue) and male Malays (green)]

Table 4: P-value of Chi-square test computed by using the full fingerprint data for assessing ethnic and sexual differences

Finger	Ethnicity (n=200)		Sex (n=200)	
	9-Class	3-Class	9-Class	3-Class
Full data				
R1	0.058	0.636	0.413	0.562
R2	0.395	0.339	0.005	0.023
R3	0.310	0.052	0.525	0.816
R4	0.765	0.357	0.037	0.159
R5	0.295	0.106	0.387	0.295
L1	0.336	0.189	0.551	0.925
L2	0.208	0.022	0.091	0.010
L3	0.019	0.007	0.596	0.612
L4	0.110	0.038	0.024	0.296
L5	0.746	0.353	0.037	0.210

reduced data produced only one pair of *p*-value less than 0.05, i.e. by using L2 of Chinese subjects (Table 5). This presented evidence that Chinese males and females could be discriminated based on the index finger of left hand.

Correspondence Analysis

In order to gain more insights into sexual and ethnicity differences in the fingerprint patterns, we employed simple CA to confirm the results deriving from the descriptive and inferential statistics. CA is also known as multi-dimensional scaling or bivariate network analysis. It aims to assess the strength of association

Table 5: P-value of Chi-square test computed by using the truncated fingerprint data for assessing sexual difference by the three ethnic groups

Finger	Chinese		Indians		Malays	
	n=66	n=64	n=68	n=63	n=66	n=59
Reduced data						
R1	0.493	0.919	0.560	0.669	0.597	0.788
R2	0.263	0.217	0.338	0.376	0.061	0.052
R3	0.601	1.000	0.584	1.000	0.559	0.851
R4	1.000	0.949	0.290	0.219	0.218	0.226
R5	1.000	1.000	0.927	1.000	0.111	0.155
L1	0.509	0.620	0.565	1.000	1.000	1.000
L2	0.029	0.024	0.341	0.382	0.074	0.098
L3	0.432	0.700	0.771	0.718	0.324	1.000
L4	0.458	1.000	0.559	0.310	0.622	0.870
L5	0.407	0.498	0.234	0.329	1.000	1.000

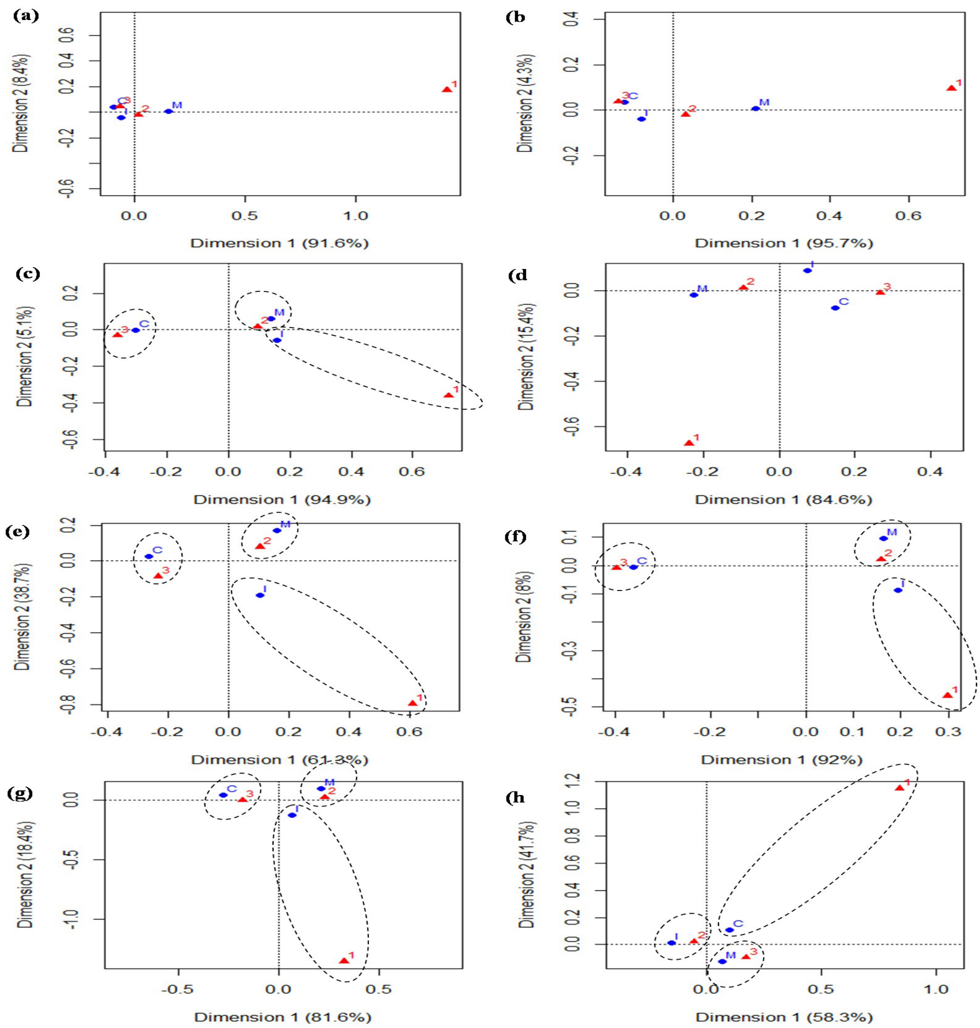

Figure 5: Analysis of correspondence between the fingerprint types [arch (1), loop (2), whorl (3)] and the ethnic groups [Chinese (C), Malays (M), Indians (I)] by fingers: (a) R1; (b) R2; (c) R3; (d) L1; (e) L2; (f) L3; (g) L4; (h) L5.

between the row entry and column entry of a contingency table in a graphical way. In this study, the row and column entries in the contingency table are, respectively, refers to the sex/ethnicity and the fingerprint patterns. Hence, the CA plot illustrates spatial representation of the sex/ethnicity and fingerprint patterns that preserves their similarity.

Due to the technical reason, CA conducted for assessing sexual dimorphism did not produce any 2-dimensional plot. This indirectly indicated the low level of sexual dimorphism in the fingerprint patterns. Therefore, CA was used to assess only the relationship between ethnicity and fingerprint patterns. Figure 5 and 6 show the analysis of correspondence between the three ethnic groups and the three and nine fingerprint patterns, respectively. In general, all the CA plots presented over 50% explanatory values. Firstly, the results derived from CA were in line with that obtained *via* the hypothesis tests. The three ethnic groups were well separated from each other in L3, followed by L2 and L4. The three fingers have produced *p*-value less than 0.05 (Table 4a). However, when the 9-classification system was adopted, well separation of the three ethnic groups was achieved only via L3. Thus, CA showed that L3 is the most useful finger in predicting the three ethnic groups.

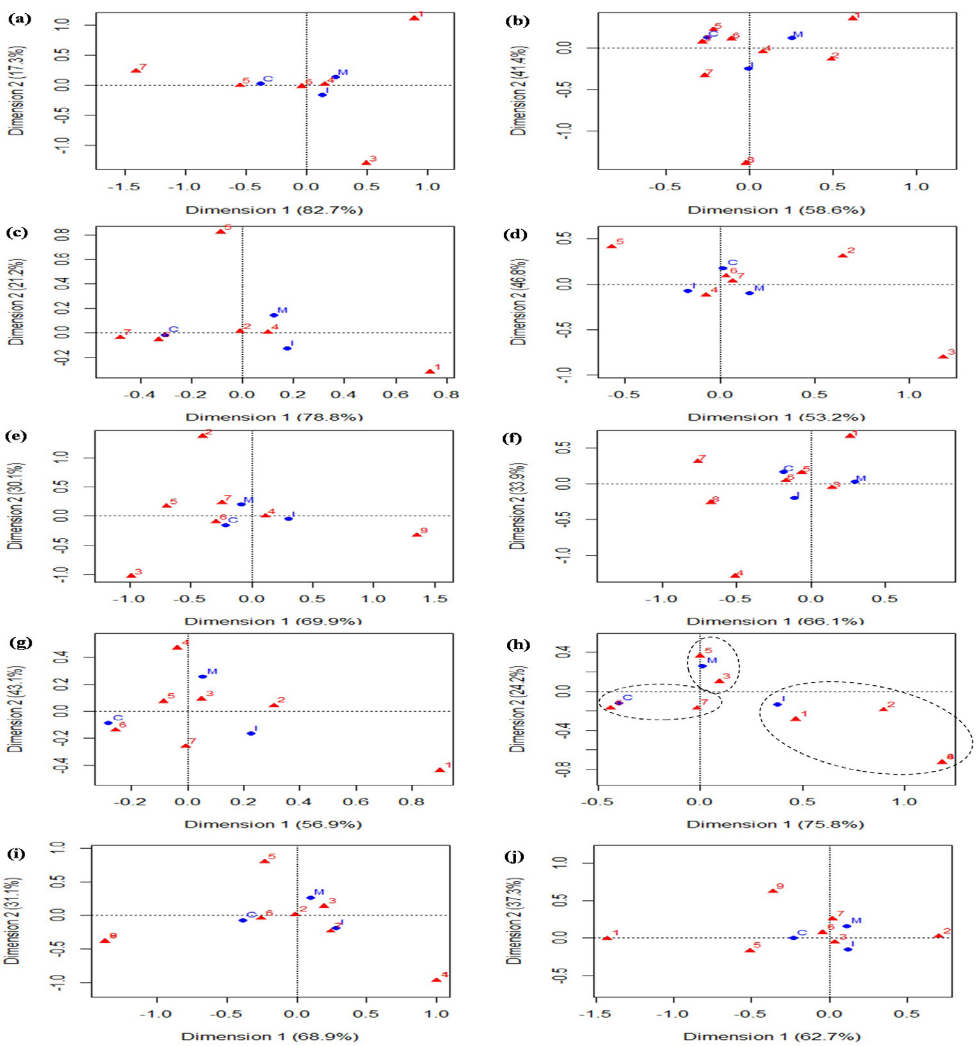

Figure 6: Analysis of correspondence between the fingerprint types [plain arch (1), tented arch (2), ulnar loop (3), radial loop (4), double loop (5), plain whorl (6), central pocket loop whorl (7), accidental whorl (8), unknown (9)] and the ethnic groups [Chinese (C), Malays (M), Indians (I)] by fingers: (a) R1; (b) R2; (c) R3; (d) L1; (e) L2; (f) L3; (g) L4; (h) L5.

DISCUSSION

In the present work, loop was the most common pattern in all the three studied ethnic groups in Malaysia. The statement is also true in other populations like Spanish and Argentinians (Gutierrez-Redomero et al. 2012), Duwakot, Bhaktapur, Nepal (Shrestha & Malla 2019) and Indian (Binorkar & Kulkarni 2017; Khadri et al. 2013; Nithin et al. 2009; Sagun et al. 2016); Sinhalese individuals (Wijerathne et al. 2013) and Thai adolescents (Nanakorn et al. 2013).

Apparently, the most useful dermatoglyphic feature for sexual dimorphism is the fingerprint ridge density (Ahmed & Osman 2016; Oktem et al. 2015; Rivalderia et al. 2016). In contrast to fingerprint ridge density, sexual dimorphism on pattern type was seldom reported in the literature. Despite that, Gutierrez-Redomero et al. (2008) once reported that there was no significant association between gender and the type of general pattern in 200 individuals of the Spanish Caucasian population. Meanwhile, Fournier & Ross (2016) examined the effect of sex, ethnicity and pattern type on minutiae variation in 243 Americans. The authors concluded that sex was an insignificant factor but the minutiae variation was significantly affected by ancestry and pattern type. In the present work, sexual dimorphism on fingerprint pattern was least apparent in Indians, followed by Malays. Males and females from Malays and Indians were showing highly similar frequencies of arches, loops and whorls. In particular, both Indian males and females presented same frequency of arches and loops. However, Chinese males and females showed different frequency of occurrence in the fingerprint pattern on left index finger (p-value <0.05).

Recently, Walton et al. (2019) documented the fingerprint pattern variation by biogeographical ancestry group, i.e. European, Middle Eastern and South Asian. The researchers found that Europeans was similar to Middle Eastern and South Asian groups in frequency of selected fingerprint patterns. Our findings indicated that the Chinese was quite different from the Malays and Indians. Meanwhile, Malays and Indians were similar with each other in frequency distributions of fingerprint patterns. Teng and Tan (1979) once reported that there was evidence of gene flow from Indians to Malays in Malaysia.

In brief, this work found ethnicity difference is much pronounced than the sexual dimorphism on fingerprint pattern. Inherently, sex is governed by the XY chromosomes but individuals originating from the same ethnic group are believed to have more similarity in terms of genetic makeup. According Muller-Ford (2004), fingerprint patterns was likely to be a heritable phenotypic expression. Therefore, our finding was supported by the fact that genetic governed factor, i.e. ethnicity, is better be characterised by fingerprint pattern whereas sex is less varied in terms of fingerprint patterns.

This work had several limitations. Firstly, we must admit that the sample size of this work was rather small. Most of the work devoted to fingerprint study employed more than 200 subjects, e.g. 500 (Nithin et al. 2009) and 2134 (Nanakorn et al. 2013). As a result, the effect of sex and ethnicity can only be studied using the 3-classification system to ensure each pattern was represented by sufficient number of subject. However, in practice, most works classified the fingerprint into arch, radial loop, ulnar loop, whorl (e.g. Gutierrez-Redomero et al. 2008; Nithin et al. 2009). Last but not least, we estimated only one dermatoglyphic index, i.e. fingerprint pattern, for assessing sexual dimorphism and ethnic difference. In future study, we shall consider other dermatoglyphic indices, e.g. Furuhata's Index, Dankmeijer's Index and Pattern Intensity Index (Barya & Krishan 2020) to evaluate the effect of sex and ethnicity on fingerprint pattern.

CONCLUSION

This study explored the sexual and ethnic differences on fingerprint patterns in a Malaysian sub-population. Fingerprint patterns could be a useful indicator for discriminating Chinese from Malays and Indians. The 3-classification system is much feasible than the 9-classifiaction system in forensic investigation for inferring the ethnicity of the unknown fingerprint. Sexual dimorphism in Chinese ethnic group is worthy of further investigation.

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